THE MORPHOLOGY AND SEDIMENT TRANSPORT

DYNAMICS OF THE SEVEN MILE BEACH SPIT

Emma J. Watt

A thesis submitted in partial fulfilment of the requirements of

Bachelor of Science (Honours)

November, 1999

Department of Geography and Environmental Studies,

University of Tasmania

Declaration

This thesis contains no material which has been accepted for the award of any other degree or graduate diploma in any tertiary institution, and to the best of the author's knowledge and belief, the thesis contains no material previously published or written by other persons, except when due reference is made in the text of the thesis.

EJWatt ....

Emma J. Watt
Department of Geography
and Environmental Studies,
University of Tasmania
November, 1999

Abstract

Sandy coasts and dune systems are dynamic and changing environments. A study on the morphology and sediment transport dynamics of the Seven Mile Beach spit in south eastern Tasmania supports this notion. The Seven Mile Beach spit is a mid-bay spit that projects into the waters of Frederick Henry Bay and Pitt Water, the mouth of the drowned Coal River Valley. The spit contains significant coastal dune features, including bare mobile dune ridges and over-steepened dunes covered with marram grass.

A combination of aerial photography and GIS analysis, demonstrated that significant changes in shoreline position and land cover type have occurred to the spit during the past fifty years. During this period, it was found that the toe of the spit was migrating east, while episodic retreat on the southern side and deposition on the northern side occurred. Analysis of land cover change indicated that marram grass has been particularly successful in colonising the area. Marram grass cover increased during the fifty year period from 15% to over 50% of the study area, displacing areas of native vegetation and bare sand .

Field monitoring techniques provided primary data on sediment transport dynamics at the study site. Results indicate that there were significant differences between sand transport at bare and marram grass covered sites, and in the amount of sand transported at different elevations above the surface. The proximity of the sample sites to the active dune system also influenced the amount of sand deposition. Erosion pin data and the monitoring of a highly mobile dune slip face illustrated that sediment transport is influenced by wind direction and strength and the presence of vegetation.

This study highlights that coastal dune systems are naturally unstable and dynamic environments, and that this complexity should be considered in the management of these features.

Acknowledgements

I would like to take this opportunity to thank a number of people, for without their contribution, the completion of this thesis would not have been possible. Firstly I would like to thank my wonderful supervisor Dr. Kate Brown for her incredible patience, time and support and for putting up with my stress attacks throughout the year. I wish to thank David Steane and Mike Pemberton for providing me with ideas and a field site for my honours topic – without this initiation I may well still have been contemplating what to do! Thanks must also go to Richard Koch and Peter Mooney of the Parks and Wildlife Service at Seven Mile Beach, for providing me with an access key to enable me to drive to my field site, and also providing me with maps so that I didn't get lost.

Many thanks must also go to my lovely field assistants (Zo, Lizzy, John, Nick, Anthony and Megs) for coming kayaking and four-wheel driving, and for putting up with being sand blasted for several hours whilst measuring sand dunes! Special thanks to Frances Mowling, who gave much of her time and offered her vehicle (even if we did get it bogged), when the Uni car was booked out and there wasn't time to kayak!

I am especially grateful to Dr. Eleanor Bruce and Advanced GIS students Sue Jungalwalla and Claire Livesey, for giving of their time and experience to generate maps, and for their patience when explaining the technicalities of the computer program to me.

I am extremely grateful to all the staff and postgrad. students in the Geography Department who helped in some way, and for providing cake on Wednesdays! I am particularly grateful to the computer technicians Mike and Dave for coming to the rescue, when the computer decided to have a break down (as soon as I got anywhere near one) on countless occasions throughout the year, and for putting up with my lack of computer knowledge. Thanks to Peter Cornish for preparing field equipment for me with skill and speed at such short notice.

The year would not have been the same without the people in the honours room (Georgie, Luke, Nick, Elizabeth, Micah and Belinda), so thanks to you all for your entertainment, sense of humour and pieces of wisdom throughout the year. Thanks must also go to the honours room lolly jar for sustaining me in desperate times and for miraculously refilling itself on becoming empty! Thanks also to my rock loving friends in geology (who I left behind on the ground floor) for all the fun and laughs over the years and for your company during those last crazy days before the thesis was due! Uni. just wouldn't have been the same without you all.

Finally, I would like to thank my especially wonderful friends and family for their support and understanding, for making me laugh and bringing me flowers and stress relief. Thanks also to my friends from afar, for sending me postcards from exotic looking places around the world. I am extremely grateful to my caring parents and wonderful sister, who brought me chocolate and surprises and whipped up dinners upon request. I thank you for putting up with me over the past few weeks and for all the support you have given me (both financially and emotionally).

I am sure that there are many people who I have failed to thank who may have helped me in some way or other throughout the year, so I thank you all for help aswell!

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The dynamic nature of the coastal environment, and the numerous processes that operate within a particular system, contribute to an array of diverse landform patterns and features. For coastal management and conservation to be effective, we must first understand the nature of the coastal environment, and the interaction of different processes operating within it. Coasts and dune systems are naturally unstable and continually changing systems, and are arguably the most dynamic landforms in Tasmania, prone to extremely rapid change (Cullen, 1998a). It is this factor that must be acknowledged when considering coastal conservation. The morphology (shape) and dynamics (movement) of the coastline are determined by the interplay of several factors including the level of wind and wave energy, rates of sediment supply and vegetation cover (Pemberton and Cullen, 1997).

Tasmania is an island state, influenced by many extremes of weather patterns, ocean swell and currents. As a result, Tasmania has a great diversity of coastal dune morphologies including transverse beach ridges, transgressive dunefields, longitudinal dunes, parabolic dunes, barrier dunes, bay-head and river mouth dunes, bay mouth spits and mid bay spits (Bradbury, 1993; Pemberton and Cullen, 1997). The total length of the Tasmanian coastline is 4792 km, with important coastal dune systems occurring along 1350 km of the coast. Of this, only approximately 100 km of sandy coast is securely reserved within National Parks, mostly in the south-west of the state (Pemberton and Cullen, 1997). Sandy coasts and dune systems (including those reserved in National Parks) are extremely vulnerable, and subject to many human induced threats and changes.

Some of the notable impacts on sandy coasts in Tasmania include recreational activities, (such as trail bike riding, horse riding and 4WD vehicles), burning, grazing, construction of groins and sea walls, and sand extraction. Perhaps more significant though, are the effects of techniques used in the past to stabilise mobile coastal dunes, which have resulted in the alteration of natural coastal processes. Such practices include the introduction of several exotic sand binding plants to many parts of the Australian and Tasmanian coastlines, resulting in the widespread occurrence of species such as *Ammophila arenaria* (marram grass), *Cakile maritima* (sea rocket), and *Euphorbia paralias* (sea spurge) along foredunes of south-eastern Australia. A growing awareness of the impacts that these exotic species are having on our coastal land forms and ecosystems is developing, along with a realisation that understanding the consequences and impacts of a management action on coastal processes and sand transport is mandatory for future coastal management.

At Seven Mile Beach, a complex and dynamic coastal sandy ecosystem exists that is influenced by a number of natural physical processes and also human activities. The introduction of marram grass in the early 1900s to Seven Mile Beach, (for the purposes of dune stabilisation) has had significant impacts on many components of the coastal dune ecosystem. Major impacts on the coastal landforms, native vegetation cover and habitats of significant fauna species such as the hooded plover (*Charadus rubicollis*) have occurred in the Seven Mile Beach area, as a result of this introduction.

1.2 PREVIOUS STUDIES ON THE AREA

There have been several studies conducted on the Seven Mile Beach land system and surrounding environments. Geomorphological studies and investigations on sea level fluctuations have been studied extensively at various locations around the region of Seven Mile Beach. Early studies of this nature were conducted by Davies (1958) and Bird (1968; 1984), and include detailed work regarding sea level change and shoreline development in south-eastern Tasmania. The curved beach outline of Seven Mile Beach has been used as a 'text-book' example of the relationship between the patterns of approaching waves and the subsequent outline of many beaches that arises (Bird, 1968; 1984).

Several other geomorphological and coastal studies have been conducted in the area, including a study on the conservation of landforms of coastal origin by Kiernan (1997). The area has been classified as an extensive and significant Spit land system by Davies, (1988) as part of a resource classification survey of land systems of south-east Tasmania. The entire spit (including sedimentary, aeolian and marine coastal features and landforms) has also been listed as being an outstanding example of a mid-bay spit for Tasmania (Bradbury, 1993; Dixon, 1995).

Several contracted reports have also been written on the region, detailing the geology (Leaman, 1971), hydrogeology and ground water supplies of the Seven Mile Beach spit (Cromer, 1976).

More recently, further research has been conducted on the area through the development of the Seven Mile Beach Management Plan (1996) by Hepper Marriott and de Gryse Pty Ltd. The production of the management plan involved providing comprehensive documentation of all aspects of the area, including: natural and cultural values; past and existing uses; and management recommendations.

1.3 AIMS AND OBJECTIVES

The primary purpose of this study is to assess the past and present morphology of the eastern end of the Seven Mile Beach Spit, and document the interaction between form, process and the influence of vegetation on bedform features. Within this broad aim the project considers four main aims:

1) The first aim is to examine the shoreline changes that have occurred to the eastern end of the Seven Mile Beach Spit since 1948, using aerial photography and GIS computer programs.

2) The second aim of the project is to map the changes in land cover that have occurred on the eastern end of the spit since 1948 (when the area was first covered by aerial photography), focussing particularly on the spread of the exotic species' *Ammophila arenaria* (marram grass) and *Pinus radiata* (Monterey pine).

3) The third aim is to determine whether the introduced species *Ammophila arenaria* is altering or affecting sediment transport processes on the spit at Sandy Point, and its influence on dune form.

4) Finally, the fourth aim is to assess the rate of sediment movement and dune migration on the spit at Sandy Point, examining changes in surface elevation (erosion and deposition) and changes in the morphology of macro scale bedform features.

1.4 STRUCTURE OF THESIS

This thesis consists of six chapters. The first chapter provides a general background to the coastal environment, focussing on the Tasmanian coastline, and the influence of exotic dune species on coastal processes and dune forms. It provides an account of previous studies conducted in the Seven Mile Beach region, and establishes the aims and objectives of the project.

Chapter 2 describes the study area at Seven Mile Beach, and provides a description of the significant biological, cultural, geological, geomorphological and climatological features of the area. The history of land use and present land use of the area are also included.

Chapter 3 provides a review of the processes operating within coastal dune systems and the formation of coastal morphological features, including the formation of spit landforms. The chapter also emphasises how such processes might influence the Seven Mile Beach Spit. The influence of introduced species (particularly *Ammophila* *arenaria*) on the formation and morphology of coastal dune systems is also discussed.

Chapter 4 provides an assessment of the long term changes to land cover and shoreline, that have occurred on the Seven Mile Beach Spit since 1948. The invasion and impacts of marram grass and pine trees on the spit is also discussed.

Chapter 5 describes the series of field experiments conducted to assess sediment transport and the rate of dune migration occurring at Sandy Point, in relation to wind characteristics and the presence or absence of marram grass.

Chapter 6 summarises the significant findings of the study and presents the conclusions and recommendations for future management of the Seven Mile Beach Spit.

CHAPTER 2

BACKGROUND TO STUDY AREA

The purpose of this chapter is to provide an overview and description of the study area, including geographical setting and landscape, flora and fauna, history and cultural values, past impacts and uses, and the geodiversity and biodiversity conservation values of the Seven Mile Beach Protected Area.

2.1 LOCATION AND ACCESS

The Seven Mile Beach spit is located approximately 20 kilometres east of central Hobart. The spit lies at the head of Frederick Henry Bay and the entrance to Pitt Water, which has become semi-enclosed as a result of the growth of the mid-bay spit of Seven Mile Beach. Figure 2.1 shows the location of Seven Mile Beach, while Plate 2.1 provides an aerial view of Seven Mile Beach and surrounding area.

The spit covers an area of approximately1100 hectares and forms part of the Seven Mile Beach Protected Area, managed by the Parks and Wildlife Service, Tasmania (de Gryse, 1996). The length of the entire spit and beach is approximately 10 km, with a width of 2.5 km at its widest point. The Hobart Airport lies adjacent to the Protected Area, with the *Milford* property and other commercial, private and tourism uses also bordering the area.

The area is easily accessible from the Tasman Highway, by Pitt Water Road or via Surf Road, both of which pass through the settlement of Seven Mile Beach. Vehicular access within the Protected Area is restricted by the presence of locked gates on both Centre Road and Spit Road. These roads provide access to the commercial pine plantations and for fire protection purposes. A network of other fire trails and tracks exist in the area which are used for various recreational purposes, including horse riding, orienteering, jogging and walking. Plates 2.2 and 2.3 provide a visual representation of features within the study area. Plate 2.2 shows a view of Sandy Point from Pitt Water, and Plate 2.3 shows an extensive mobile dune ridge located at the eastern end of Seven Mile Beach.

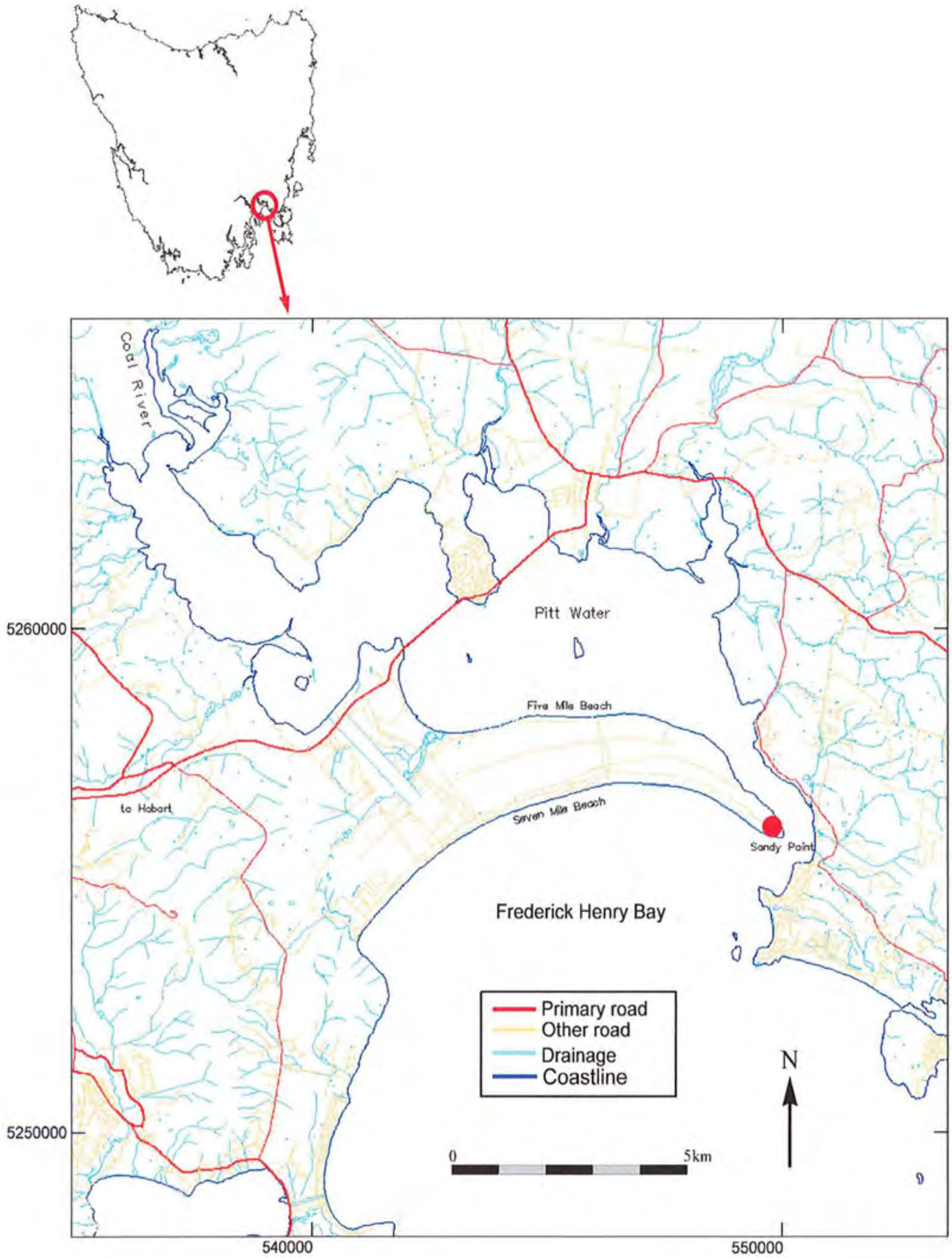


Figure 2.1 - Location of Seven Mile Beach spit and field site (indicated by red dot).

Plate 2.1 - Aerial Photograph of the Seven Mile Beach barrier system and Pitt Water Estuary, 1997. Scale: 1:42,000.

Plate 2.2 - View from Pitt Water to the dunes at Sandy Point, Seven Mile Beach.

Plate 2.3 – Aerial view of the eastern end of the Seven Mile Beach Spit, projecting into Pitt Water. Photograph taken in 1977. (After Dobson and Williams, 1977).

2.2 REGIONAL SETTING AND LANDSCAPE

The close proximity of the Protected Area to metropolitan Hobart is important, in terms of its accessibility to the residential and rural areas of the Clarence and Sorell Municipalities. The Protected Area is also adjacent to the Settlement of Seven Mile Beach (with a population of around 1000), making it accessible to a number of different potential user groups (de Gryse, 1996).

The Protected Area is important regionally as an area of multiple recreational, commercial and tourism use. de Gryse (1996) outlines the significance of the region as a multiple use area, by stating that the Protected Area is a recreational area, providing a 'diversity' of recreational activities, including activities which are not well-catered for in other public reserves in the region.

'Protected Area' is defined by the Parks and Wildlife Service (1994, p. 13), under The Crown Lands Act 1976 as being: "an area of land and/or water predominantly comprising unmodified natural systems, where provision is made for the protection and maintenance of biophysical and cultural heritage while providing at the same time potential for the sustainable use of the area's resources".

Within the Protected Area, the scale and diversity of the coastal landforms are also of significance (see plates 2.2 & 2.3), as are the biological and cultural values, which combine to contribute to its significance for conservation management. The elevation of the site ranges from sea level, to approximately 12 m elevation on the sand ridges located at Sandy Point (refer to Plate 2.3), and the Holocene beach ridges that occur inland parallel to the shore (Tasmap, 1985).

2.3 CLIMATIC CONDITIONS

The Seven Mile Beach spit area and its surrounds are considered to be temperate maritime in character, with similar conditions to that observed at the Hobart Airport. The area receives relatively low rainfall, with moderate temperatures and high evapotranspiration compared to the rest of the state (Davies, 1988).

Precipitation in the Seven Mile Beach - South Arm area is generally below 600 mm per year, with an average annual rainfall of 509 mm recorded at the Hobart Airport (42.84^0 S; 147.50^0 E), between 1958 and 1999. Figure 2.2 shows average monthly rainfall for the period between 1958-1998. It can be readily observed that there are only minor variations in monthly rainfall. Temperature averages in the area range from 12^0C in winter to 22^0C in the summer months. The highest average monthly temperatures occur during January and February, and the lowest monthly temperatures in July (Figure 2.3).

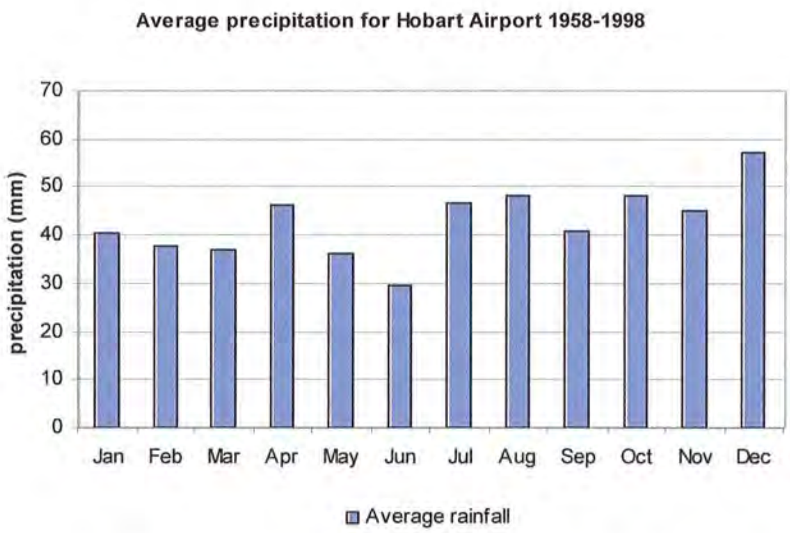


Figure 2.2 - Average monthly precipitation for the Hobart Airport using available data between 1958-1998. (Bureau of Meteorology, 1999 b)

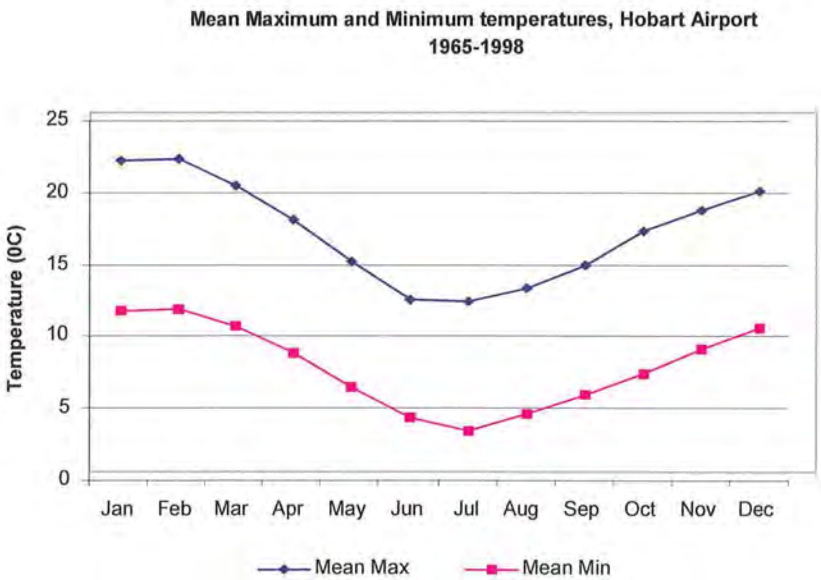


Figure 2.3 - Average monthly maximum and minimum temperatures between 1965-1998, Hobart Airport (Bureau of Meteorology, 1999b).

Wind roses were obtained, using available data for the period between 1958 and 1999. Seasonal wind roses for Hobart Airport demonstrate that north-westerly winds dominate during the morning in all months of the year, but during Spring and Summer time in the afternoon, a strong southerly or south-easterly wind predominates as a result of the developing sea breeze. During winter time north-westerly winds prevail, but direction is variable across the spectrum of north-westerlies to southerlies and northerlies. Of the four wind categories (1-10 km/h, 11-20 km/h, 21-30 km/h and > 30 km/h), north-westerly winds greater than 30 km/h persist in all seasons, but occur more frequently during the spring time. Wind roses for summer, autumn, winter and spring for the Hobart Airport, and averaged across the period of 1958-1999, are presented in Figure 2.4.

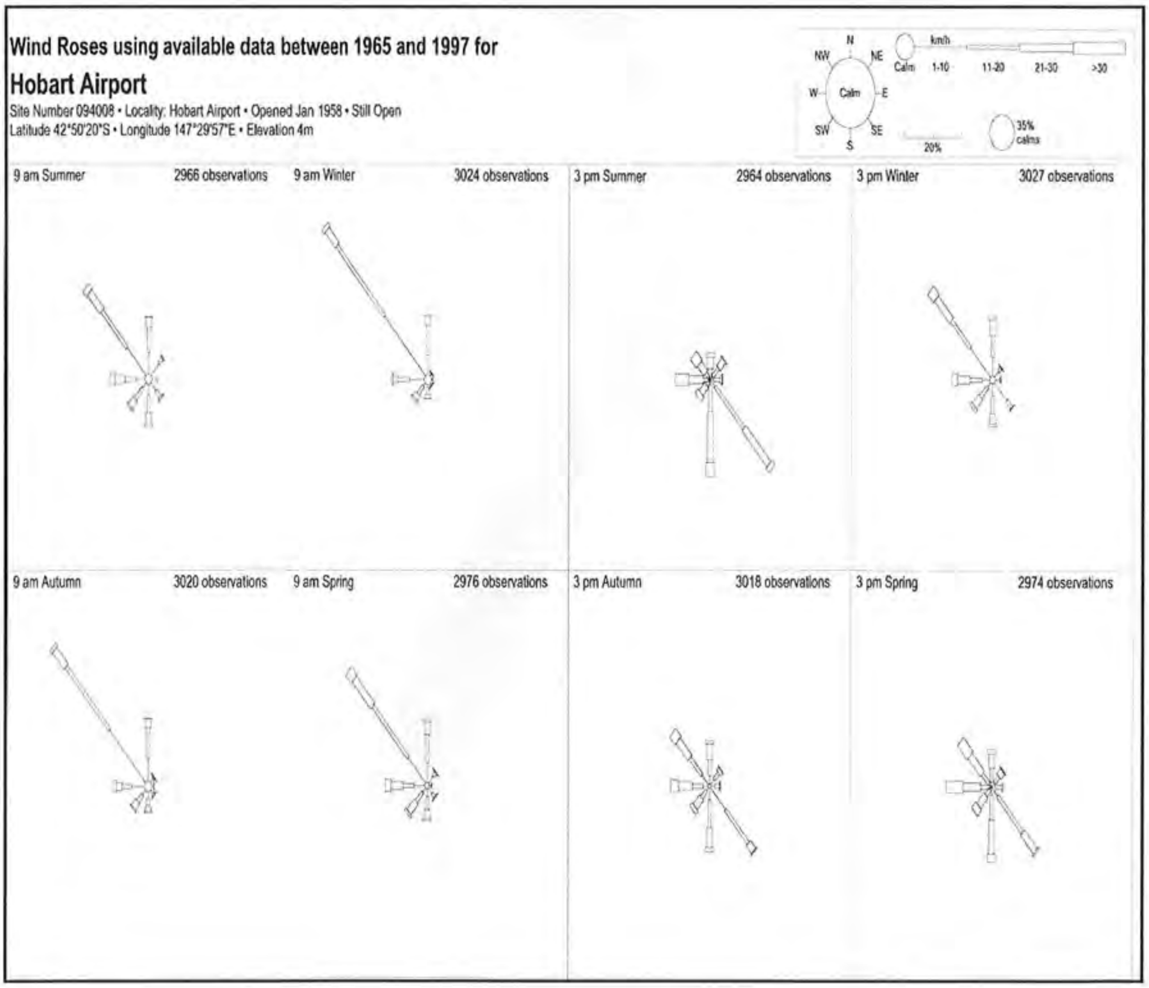


Figure 2.4 - Wind Roses for the Hobart Airport, averaged between 1958 and 1999. (Bureau of Meteorology, 1999b).

2.4 GEOLOGY AND SOILS

The geology of the region surrounding Seven Mile Beach has been mapped by Leaman (1971) as part of the study of the geology of the Coal River Basin. Single Hill to the south-west of Seven Mile Beach is composed of a complex of Jurassic dolerite dykes, intruding Permian sandstone and siltstone. At Hobart Airport and east Barilla Bay, Triassic sandstone outcrops occur. Figure 2.5 shows the geology of the study area and surrounds.

The Seven Mile Beach spit consists entirely of unconsolidated Quaternary aeolian, marine and estuarine sands, overlying clays. Evidence from several augered holes and rotary drill holes show that the unconsolidated sand is approximately 13 m thick, overlying at least 70 m of impermeable green clay, probably Tertiary in age. This clay appears to underlie the entire spit at a depth between 10-12 m (Cromer and Sloane, 1976). The overlying Quaternary sequence consists of shelly-marine and clayey estuarine sands, with a rich shelly horizon at its base. The uppermost layer of the Quaternary sequence consists of a yellow-buff aeolian quartz sand cover up to 3 m thick. A granitic batholith underlies much of eastern Tasmania, being some 9 km below the surface at Seven Mile Beach (Cromer and Sloane, 1976).

Soils within the area generally show weak profile differentiation inland and are stabilised with vegetation. Some dark organic matter and sub-surface bleaching occurs. Towards the seaward extent of the spit area, the soils are actively accumulating sand which contains many shell fragments further inland (Loveday, 1955; Davies, 1988).

Cromer and Sloane (1976), through geological and hydrological studies conducted in the area, have revealed that there are no permanent streams or river systems within the spit area. This reflects the rapid infiltration of rainwater into the sandy substrate. Rainwater infiltrates into a groundwater aquifer below the surface that is in the order of 40,000 ML in volume. The unconfined aquifer has an average thickness of 10 m, extending over 10^6 m^2. The aquifer is believed to recharge at a rate of approximately 1000 ML per year (Cromer, 1996).

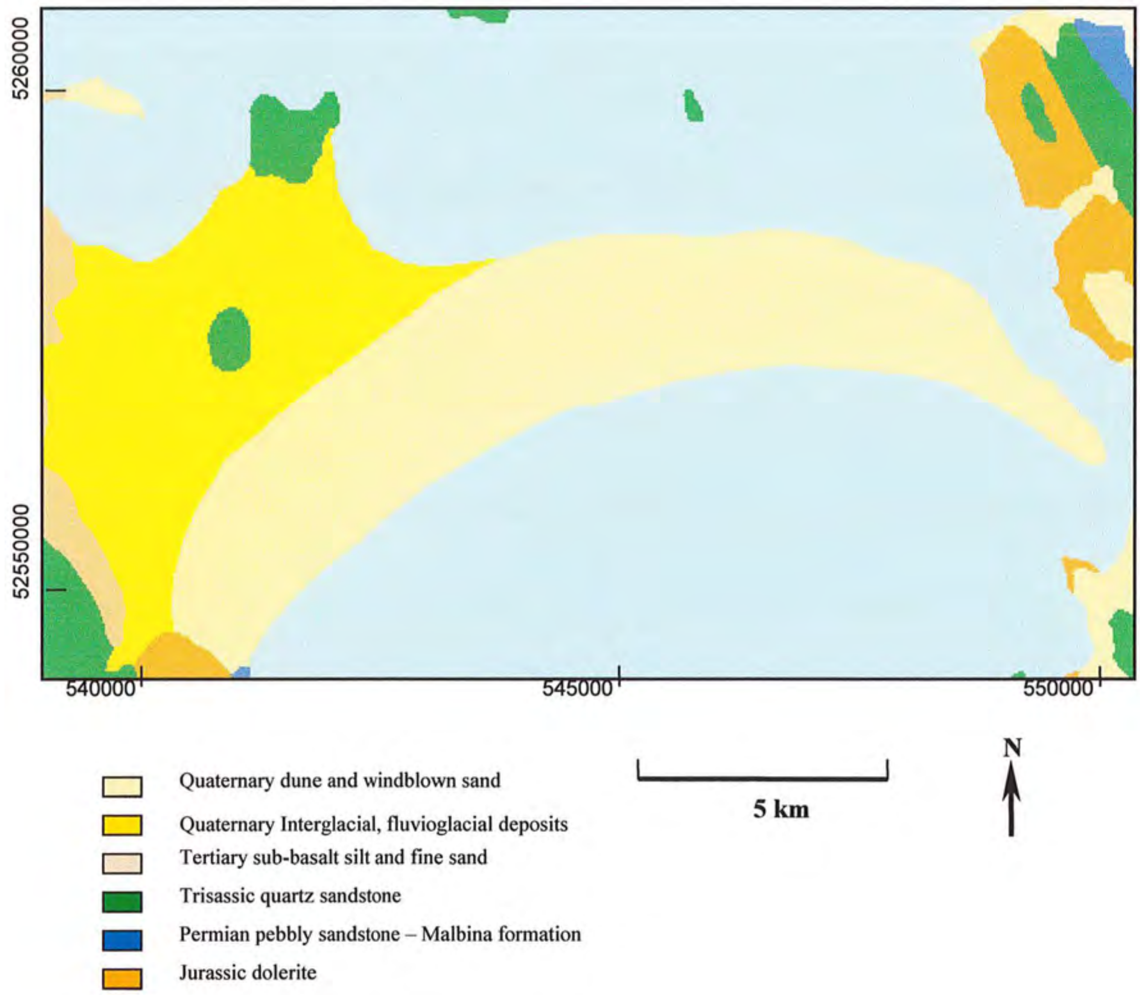


Figure 2.5 – Geology of the Seven Mile Beach region (Department of Mines, 1995).

2.5 GEODIVERSITY

The term geodiversity is defined as " the range or diversity of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes (Dixon, 1996).

The Seven Mile Beach spit and surrounds are significant in terms of geodiversity conservation, owing to the visible assemblage of coastal and aeolian geomorphological features, including:

- recent (Quaternary) beach and dune sands and tidal flats;
- older (Pleistocene) beach and dune sands;
- wind blown sand sheets;
- alluvial, lagoon and estuarine deposits;

- and sub-parallel beach ridges.

This assemblage is considered to be an outstanding example of marine and aeolian sedimentary features for Tasmania, and has been described as being of national importance (Bradbury, 1993). As such, the features are also listed in the Tasmanian Parks and Wildlife Geoconservation data base (Pemberton, pers., comm., 1999). The site is important as an area of geoheritage significance as it displays a number of typical physical processes associated with the dynamic coastal environment, such as ongoing dune building and erosion, and soil building (de Grys, 1996).

In a review of sites of geomorphological significance in Tasmania, Dixon (1995) describes the features present on the Seven Mile Beach spit as being significant in terms of National Estate criteria. Dixon's recommendations for listing the geomorphological features of the Seven Mile Beach region under the National Estate are based on the following:

- The area is described as being the best preserved and least developed example of a mid-bay spit in Tasmania, both as a geomorphic system and its elemental features (National Estate Criterion D1);

- Seven Mile Beach has been identified as the "type section' for the last interglacial and post glacial period high sea levels (Pemberton, pers. comm. 1999; National Estate Criterion A1);

- The associations of the Seven Mile Beach area with the early seminal coastal geomorphic research in Tasmania by Davies (1958; 1959; 1963) and Colhoun (1975; 1977) (National Estate Criterion C1); and

- The significance of the area for research and educational opportunities associated with the site (National Estate Criterion C1).

The study of this particular site is to help gain a better understanding of the processes, features and landforms that contribute to the significant coastal geomorphology of the area. Plate 2.4 illustrates the scale and diversity of some of the significant coastal landforms of the area.

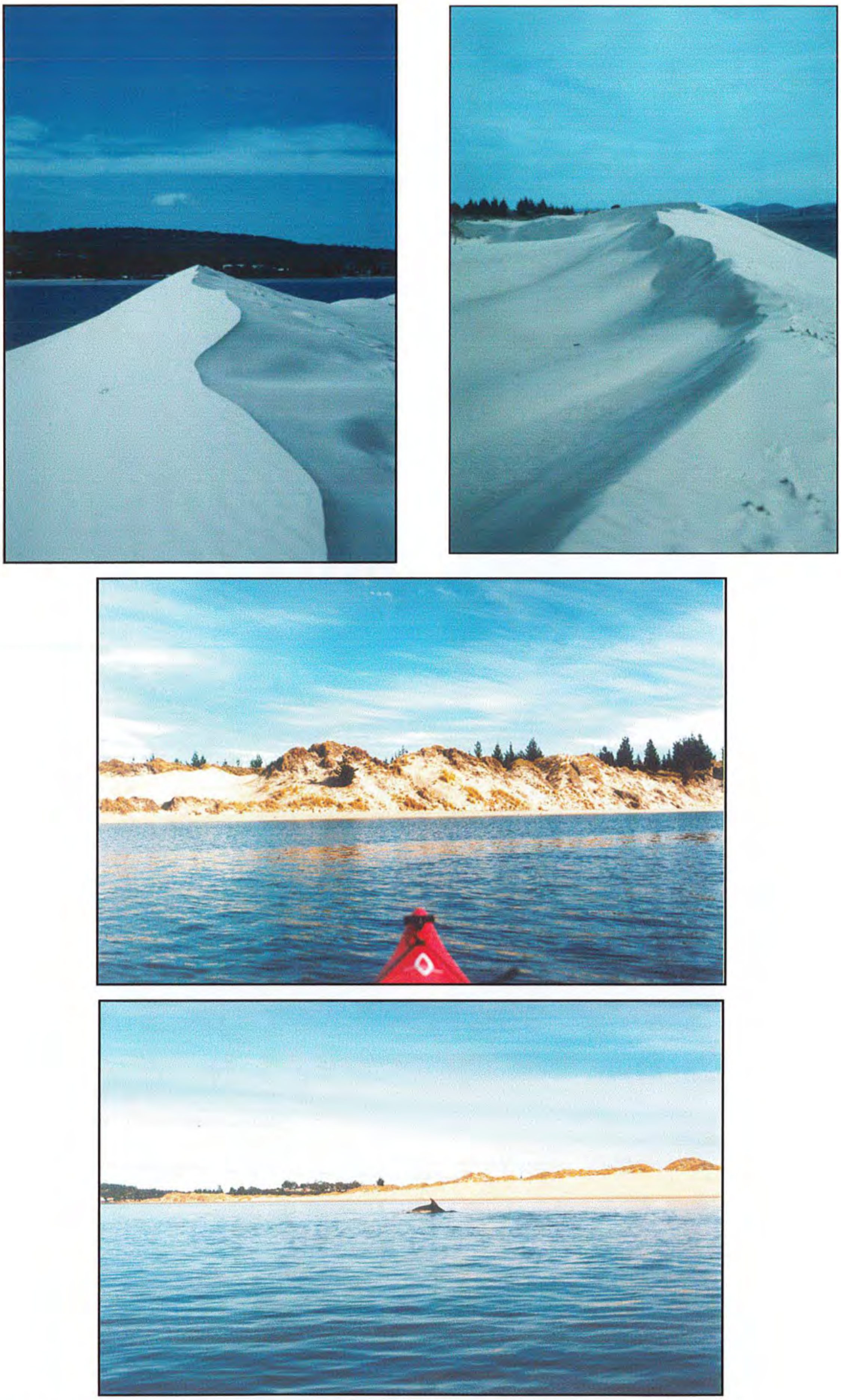


Plate 2.4 – Landforms of geoconservation significance at Sandy Point.

2.6 VEGETATION

The influence of different land use practices over the past one hundred years in the Seven Mile Beach area has had a dramatic effect on the native vegetation and plant communities. Over 90% of the area is now comprised of plant communities dominated by three exotic species: *Pinus radiata* (Monterey Pine), *Pinus pinaster* and *Ammophila arenaria* (marram grass). Patches of remnant native vegetation are scarce on the spit, and mostly have a high exotic component. As a result, the species diversity is very low, and few viable areas of natural vegetation remain. The native plant communities that do remain, are highly localised in their distribution within the Seven Mile Beach Area (Duncan, 1996 in de Gryse, 1996).

Among the native plant communities, several are listed as being of relatively high conservation significance. For example grassy *Eucalyptus viminalis* forest is of statewide, regional and local significance, but because of its small area and degree of disturbance, its significance has been diminished. Two species considered to be rare (*Cynoglossum australe* - hounds tongue), or potentially rare (*Danthonia geniculata*) in Tasmania occur within the spit area. Both species occur on disturbed sites, and in *Eucalyptus viminalis* forest (Flora Advisory Committee - FAC, 1994).

2.7 FAUNA

The Seven Mile Beach Protected Area is the home of several significant fauna species, including the hooded plover (*Charadrus rubicollis*) which is listed as "nationally vulnerable" (Garnett, 1992 and McGlone, 1999). The eastern barred bandicoot (*Perameles gunnii*), considered vulnerable nationally is also known to inhabit the area (Taspaws records). The little pygmy possum (*Cercartetus lepidus*) has also been found in the area by local residents (VAC, 1994).

Several other significant fauna species have also been observed in the area including: the wedge tailed eagle (vulnerable); little tern (nationally endangered); and six other rare species of bird (fairy tern, lesser golden plover, bar-tailed godwit, red knot, eastern curlew, great crested grebe), which live and breed on broad flat sandy beaches (McGlone, 1999). Other species, such as the Australasian gannet, pied oyster catcher, little penguin and southern giant petrel, are likely to be found in the Protected Area and require monitoring, due to a decline in numbers nationally (VAC, 1994). Seven Mile Beach is also considered a significant breeding site for the pied oyster catcher (*Haematopus longirostris*). The white breasted sea eagle (*Haliaeetus leucogaster*) also has a known occurrence within the Seven Mile Beach Protected Area (Mooney, pers. comm., 1999).

In the surrounding waters of Pitt Water and Frederick Henry Bay, marine and aquatic life is abundant. Among the more significant species observed in the area, are periodic sightings of leopard and elephant seals, bottle-nose dolphins and porpoises. Pitt Water is also considered to be one of the most important breeding grounds for gummy sharks in south-east Australia (de Gryse, 1996).

2.8 HISTORY OF LAND USE

2.8.1 Aboriginal History

The Seven Mile Beach area was once the home of the Moomairemener people, of the Oyster Bay Tribe, who occupied many coastal areas of the south eastern part of Tasmania up until European settlement began. As hunters and gatherers, the tribe utilised abundant seasonal food resources from both the land and the sea (Christensen and Jones, 1997). Little more is known about their inhabitance and use of the area. There are however a number of midden and artefact sites that have been located at Seven Mile Beach, and Five Mile Beach, some of which are quite large and testimony to the history of Aboriginal occupation of the area.

2.8.2 Early European Settlement

During the early 1800s over 500 people were evacuated from Norfolk Island and settled around the shores of Pitt Water. As a consequence, thousands of acres of land were rapidly cleared and cultivated in a period of less than five years. Settlement of the Seven Mile Beach area resulted primarily from the development of large properties and estates across the area, with many of the properties being owned by one person. For example, R. Lewis owned the properties of *Milford, Llanherne, Cilwen, Abermont* and *The Neck*, extending over much of the Protected Area and surrounding land.

By 1816, a number of ferry routes, connecting land from Dodges Ferry to Sorell and Seven Mile Beach were in operation. The two main land routes provided communication between Hobart, the eastern shore and the settlements and farms around the Pitt Water area.

The area around Pitt Water continued to be settled, with a major expansion occurring during the period between 1817-1824, when free settlers arrived. This eventually resulted in the displacement of Aboriginal people from their land, and by 1839 the last known member of the Moomairremener people died, ending the record of traditional Aboriginal life in the Seven Mile Beach area.

During the 1920s large portions of land around the eastern side of Seven Mile Beach were purchased by the Forestry Pulp and Paper Company of Australia, for the establishment of pine plantations, with the first pines planted in 1927. Further planting and felling of trees occurred for several years, before parts of the plantation were sold for other developments, such as the construction of the Hobart Airport. Loongana Saw Mills Pty. Ltd. obtained cutting rights to the existing plantation, with a sawmill operating at Cambridge up until the late 1960s.

2.9 CURRENT LAND USE WITHIN THE STUDY AREA

The Seven Mile Beach Protected Area covers an extensive area of coastal land, and provides for a range of recreational, commercial and other uses. Protected Areas are large multiple use areas, managed under the Crown Lands Act 1976, and are areas which are principally for conservation and controlled resource extraction with nature conservation values emphasised (Parks and Wildlife Service, 1994).

2.9.1 Commercial operations

Extensive pine plantations (predominantly *Pinus radiata* species) have covered most of the spit area, since the early 1900s. In the 1980s the Australian Newsprint Mills (ANM) purchased exclusive cutting rights to the existing crop of pines from the plantation. Of the original plantation (over 400 hectares) 65% has been subject to these cutting rights. Cutting of pines from the plantation will progressively occur until the year 2010, when the cutting rights are due to expire (Koch, pers. comm., 1999).

Within the Protected Area, land has been purchased from the Crown by a number of commercial business operators. A commercial equestrian centre and pony club exist at the western end of the Seven Mile Beach Spit, with a riding course and extensive riding trails developed for clients and members of the Club. Facilities such as stables, arenas, and beginner training areas have also been developed on land leased from the Crown. A thoroughbred horse training centre has also been established in close proximity to the equestrian centre, providing a training track, stables, a well maintained gravel access road and access to the beach area for training purposes.

The Department of Police and Public Safety, the Tasmanian Fire Service (TFS) and the Federal Airports Commission (FAC) also occasionally use the area for the purpose of training exercises.

2.9.2 Recreation

Recreation plays a significant role within the Seven Mile Beach Protected Area. Recreational activities currently permitted within the Protected Area include walking, horse riding, cycling, orienteering, dog exercising, water sports (eg. sailing, kayaking, surfing, fishing), fitness training, general relaxation and nature study/photography/art work. Trail bike riding also occurs illegally in the area (on and off formed trails). The spit area provides both land and water based recreational activities, thereby contributing to the diversity of activities available to the public when using the area.

According to the Hobart Metropolitan Council Association (HMCA) Leisure Survey, undertaken in 1992, Seven Mile Beach was placed as the seventh most frequently visited open air recreation venue in the Hobart region. The survey suggested that the major recreational activity undertaken in the area is dog walking (30%), followed by walking, picnicking and horse riding.

2.9.3 Tourism and facilities

A number of tourist and visitor facilities exist within the spit area, as a result of Crown land being sold to commercial operators. Existing facilities include a visitor information centre, operated by the Parks and Wildlife Service, cafe, shop, toilets and picnic/barbecue amenities.

Tourist use of the area is related to: the use of well-known accommodation such as *The Pines Resort*, which is the principle tourist drawcard; the Equestrian Centre trail rides; and the close proximity of Seven Mile Beach to the Hobart Airport, making it an ideal sightseeing option before departure.

A number of visitors and tourists also come to the area for the 'natural' qualities and setting it provides, such as the seven mile-long sandy beach. Seven Mile Beach is promoted as a "holiday playground' only 15 minutes away from Hobart, and in close proximity to other major tourist attractions such as Richmond, Tasman Peninsula and it is on route to several golf courses.

2.10 CHAPTER SUMMARY

The Seven Mile Beach spit (within the Protected Area) has a diverse array of geological, geomorphological and biological features and assemblages, with significant natural and cultural values important to the area.

The main part of the study area, located on the end of the spit at Sandy Point, consists of an extensive active sand dune complex, with elevations of up to 12 m above sea level. In the following chapter a discussion is provided regarding the formation of the Seven Mile Beach Spit and other coastal depositional landforms.

A large proportion of the study area is now covered with exotic vegetation, including marram grass (*Ammophila arenaria*) and pine trees (*Pinus radiata*). Aeolian sediment transport processes and the effects of marram grass on dune forms and processes will also be discussed in Chapter 3.

CHAPTER 3

FORM AND PROCESS

This chapter reviews and evaluates a selection of literature that discusses the formation of coastal geomorphological features, including the formation of spits and dune systems. In particular, the chapter focuses on the formation and morphology of the Seven Mile Beach bay-mouth spit, and the processes operating and systems present within this land system. The aims of this chapter are to gain an understanding of the processes operating within coastal dune and barrier systems, and to recognise the dynamic nature and resultant forms of such features. The chapter also emphasises how such processes may influence the Seven Mile Beach Spit.

Section 3.1 provides an introduction to the coastline of south-east Tasmania. The formation of spits and coastal depositional landforms are discussed in section 3.2, including the formation of the Seven Mile Beach Spit. Section 3.3 describes aeolian sediment transport processes, and resulting bedform features are described in section 3.4. The influence of vegetation (particularly *Ammophila arenaria* - marram grass) on the formation and morphology of coastal dune landforms is discussed in section 3.5 while a chapter summary is provided in section 3.6.

3.1 INTRODUCTION

The present coastline of south-east Tasmania reflects a world-wide post glacial rise in sea level (Flandrian Transgression) caused by the melting of glacial ice that had accumulated during the Last Glacial period. The sea level rise brought about the drowning of the lower reaches of river valleys including the Derwent, Pitt Water, Frederick Henry Bay, Blackman and Norfolk Bays and the consequent flooding of lowlands (Davies, 1959; Van de Geer, 1972; Goede, 1999, pers. comm.). The major part of submergence occurred between 12,000 and 6,000 years ago, when there was a rapid rise in sea level.

The present sea level along the Australian coastline was reached about 6000 years ago. Since this time there have been only minor fluctuations, with no convincing evidence that sea level was significantly higher than today at any time during the last 6,000 years (Murray-Wallace and Goede, 1995).

The following sections discuss the formation of spits and other depositional coastal barrier forms, with emphasis placed on the formation and morphology of the mid-bay spit at Seven Mile Beach in south-eastern Tasmania. The development and formation of coastal dunes will also be considered, as dunes form a major component of the landform features present on the Seven Mile Beach Spit.

3.2 FORMATION OF SPITS AND OTHER COASTAL DEPOSITIONAL FORMS

Spits are elongated low-lying depositional landforms, attached at one end to the mainland and terminating at the other in deeper water. They often develop where the coast changes direction (King, 1958; Moffatt, 1991; Summerfield, 1993). Hardisty (1990) states that spits are separated from the mainland by a narrow channel of water or marsh, and extend roughly parallel with the general coastal trend. Spits that extend down current from headlands may reflect longshore currents and longshore sediment transport caused by waves (Tasmanian Conservation Trust Inc., 1978).

Bird (1968) defines spits as being depositional features built along the shore, often ending in one or more landward hooks or recurves (Scwartz, 1972). Recurves, which are a common feature of many spits as well as some barrier islands, form at their accreting terminus (Davies, 1959; King, 1959; Bird, 1968, 1984). The recurves develop either as a result of the interplay of sets of waves arriving from different directions or by wave refraction around their distal ends, and often form where the ends of spits project into exposed waters, as seen in Figure 3.1 (Bird, 1967, 1984; Davies, 1972; Kiernan, 1997). Worldwide, most spits are recurved features. However, of the 19 major spits around the Tasmanian coast, only two are prominently recurved, including Rheban Spit on the east coast of Tasmania and Marion Bay spit in the south-east of the state (Bowman, 1986; Kiernan, 1997).

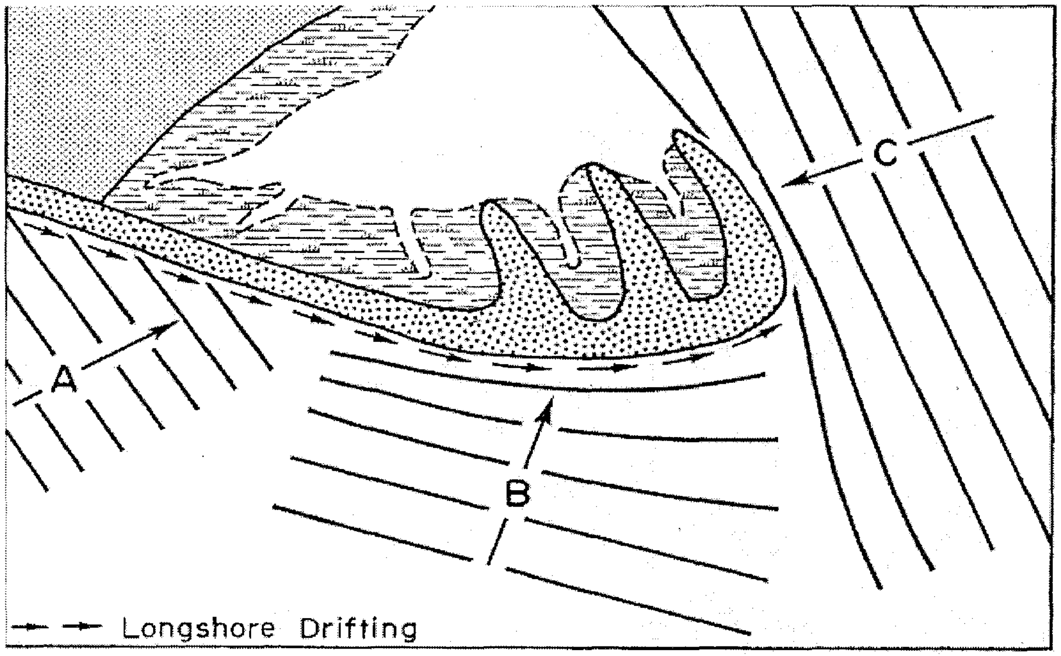


Figure 3.1 - The shaping of a recurved spit (Hurst Castle Spit, south England). Waves coming from direction A arrive at an angle to the shore, creating longshore drifting that supplies sediment to the spit; waves from B and C determine the orientation of its seaward margin and the orientation of the recurved point (after Bird, 1968, 1984).

According to King (1959), spits commonly occur on coasts that have an irregular outline with frequent change in orientation. In addition spits often form across the mouths of estuaries or rivers, either completely or partially closing them off to the sea (Moffatt, 1991). River mouths and lagoon entrances are often deflected by the formation and growth of spits, being prolonged in the direction of longshore drift (Bird, 1984; Moffatt, 1991). Behind many spits, expanses of marsh areas or tidal mud and sand flats are common, protected from the influence of swell waves.

Longshore drift is a major process involved in the formation of spits, and reflects the process of sand being deposited, as it enters a zone of slack water (King, 1959; Davies, 1959; Bird, 1968, 1984; Moffatt, 1991; Kiernan, 1997). The process of longshore drift supplies material which is built into the spit through the action of different processes varying with the character of the beach material (King, 1959). The significance of longshore movement and the importance of beach-drifting in the building of spits above water level, was recognised by early geomorphologists such as Evans (1942).

Whilst it can be noted that currents may contribute sediment to spit formation, the outlines and forms of spits can largely be attributed to wave action, growing in the direction of longshore sediment transport caused by waves (Bird, 1967, 1983).

Widening of spits occurs by the addition of successive ridges on the seaward side. As a result of this, stages of spit evolution can be deduced from the pattern of beach ridges. For example Rheban Spit at Carrickfergus Bay, on the east coast of Tasmania shows a series of beach ridges that are angled in differing directions as a result of changing wave induced current directions in the sea (Davies, 1959; Bird, 1968; 1984; Bowman, 1986).

The shape of a growing spit, can also be influenced by the space available for its growth, and by the adjacent sea floor topography. Spits generally grow more rapidly in shallow areas than in deep water, with differing exposure to wave action relating to their configuration (Bird, 1984).

Summerfield (1993) suggests that where there is a constant unidirectional swell wave regime, concave rather than convex spits can develop. This situation is exemplified along the southern coast of Australia, for example the Seven Mile Beach Spit, which is discussed further in section 3.2.1.

A number of different types of spit morphologies may exist. Bay mouth bars are features similar to spits except that they extend into a bay rather than the open ocean, and are protected from the influence of large swells and storm waves (Summerfield, 1993). Most Tasmanian spits are composite structures made from the accumulation of beach ridges (discussed further in section 3.2.1), with a varying degree of sand masking (Tasmanian Conservation Trust Inc., 1977-1978).

Other depositional barrier forms include tombolos, which are spits that have grown to connect an island to the mainland (Bird, 1984). There are many examples of tombolos linking two islands together in Tasmania, for example Bruny Island in the south east of the state and Maria Island off the east coast (Burns, 1977; Bird, 1984).

3.2.1 Evolution of the Seven Mile Beach spit

The Seven Mile Beach Spit is a mid-bay spit or bar (Davies, 1959; Summerfield, 1993, de Gryse, 1997) and is composed entirely of sand, backed by foredunes and transverse beach ridges (Davies, 1959; Cromer, 1976; Chick, pers. com. 1999). The spit is a consequence of the Holocene marine transgression and appears to have grown from west to east, orientated to the refracted swell waves which move up Frederick Henry Bay (Hurburgh, 1973; Bird, 1984).

At Five Mile Beach (at the back of the Seven Mile Beach Barrier system, see Figure 2.1), Murray-Wallace and Goede (1991) have described a site where beach sediments occur up to 1.5 m above HWM. Their elevations, however, are explained as being due to higher wave exposure, as at that time the site would have been open to wave action from Frederick Henry Bay. The sediments have been found to contain a mixture of Holocene and Last Interglacial shells, indicating the presence of Late Pleistocene beach and marine sediments in the area, that were being reworked as the first Holocene beach ridge was constructed (Goede, 1998). Figure 3.2 shows the likely evolution of the Seven Mile Beach peninsula and dune ridges during the Holocene period.

According to Davies (1959), the Seven Mile Beach Spit appears to have grown from west to east due to three main factors:

1) The presence of the initial peninsula on the western shore of Pitt Water.
2) The prevalence of beach drifting from west to east under the influence of local waves generated by south-west winds.
3) The decrease in wave height and consequently berm height from west to east, caused by refraction of the dominant swell.

Refraction diagrams and berm height inspection of the present beach, have indicated that beach drifting appears to be negligible, and the western peninsula is only there because the spit also grew from the west (Davies, 1959).

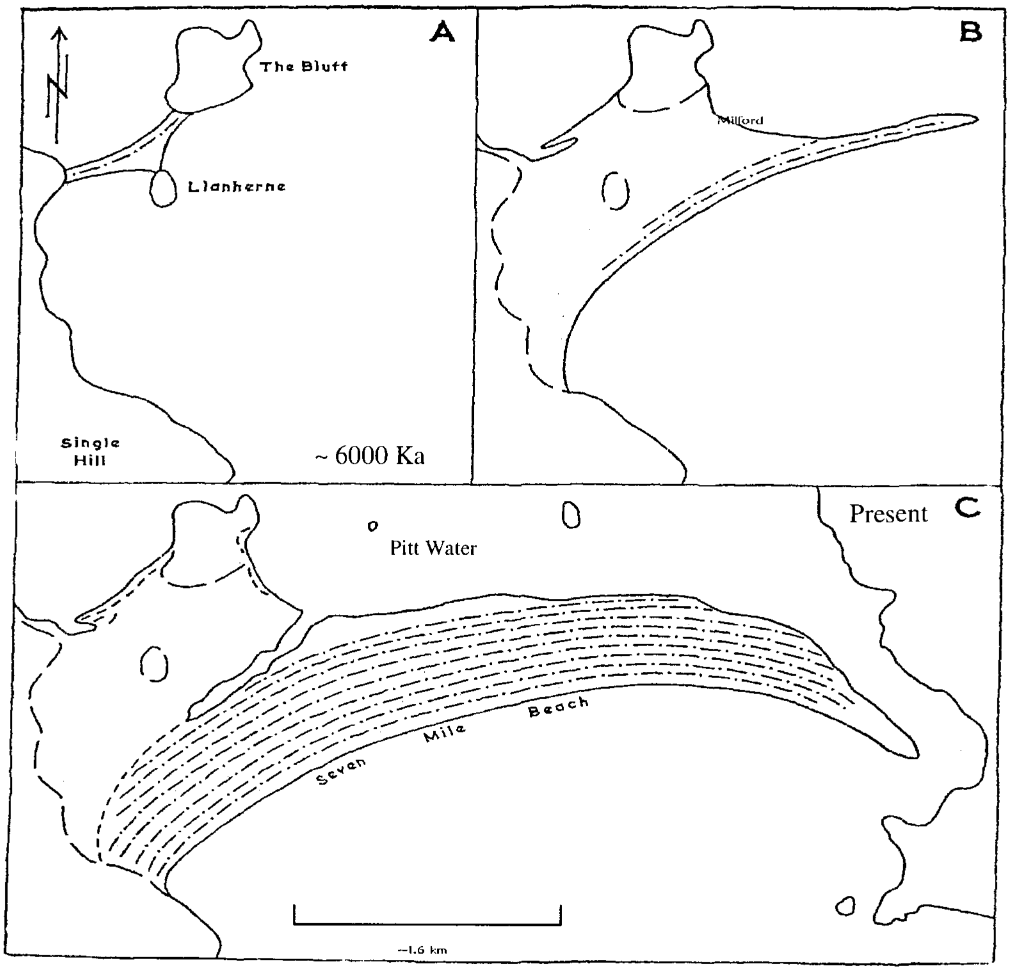


Figure 3.2 - Evolution of the Seven Mile Beach peninsula during the last interglacial period at times of two higher sea levels. The dashed lines indicate the position of foredunes and beach ridges. On the present day map, only every fifth ridge is shown. Diagram A: indicates the likely situation when the Holocene sea level reached present day sea level about 6,000 years ago. Llanherne Hill (airport control tower) and The Bluff may have been connected by degraded last Interglacial beach and shallow marine deposits. Diagram B: shows the initial evolution of the Seven Mile Beach barrier system a short time later, as initial progradation would have been rapid due to an abundant sediment supply pushed onshore during the Flandrian Transgression. Diagram C: shows the present configuration of the Seven Mile Beach spit. The presence of a high foredune indicates a long period of shoreline stability. Beach ridge formation across the barrier system possibly ceased several thousand years ago as the sediment supply diminished.

3.2.2 Geomorphological influence of the Southern Ocean Swell

The southern coast of Tasmania is dominated by a continual low, long south-westerly swell, with a 12-14 second period. This swell pattern has been invoked to explain general beach alignment in southern Australia (Davies, 1959; 1960). The spit at Seven Mile Beach acts as a barrier to the swell waves, and therefore prevents such waves from entering Pitt Water. The waves generated in Pitt Water are therefore as a result of local winds producing waves with a 3-5 second period and an amplitude of one meter (Hurburgh, 1973).

The direction in which the swell will travel is determined by the direction of the generating wind, and the distribution of recent aeolian sands reflects the dominant wind directions. Davies (1959) has shown that in south-east Tasmania south-westerly swell becomes refracted to a southerly swell upon entering bays such as Frederick Henry Bay. Further refraction of ocean swell in Frederick Henry Bay develops outlines that fit the curved bays of the area (Bird, 1968; 1984).

Figure 3.3 provides a diagram of refraction, constructed for fourteen second south-westerly swell entering Frederick Henry Bay. The diagram provides further evidence that swell reaches Seven Mile Beach parallel to the shore, and that this direction is determined some distance from the beach, rather than adjusting immediately before the shore. As a consequence of this, the beaches are aligned to fit the waves rather than the reverse. This is highlighted by the way the waves arrive parallel to the beach, but not to the hard rocky sections of the coastline (Davies, 1958).

Davies (1958) also notes (through the construction of wave orthogonals from deep water) that the energy of the generated swell is reduced by approximately 180 times before it reaches the beach. However, the energy of the swell entering Frederick Henry Bay is still high enough for the building of parallel lines of sand beach ridges and the beach berm that controls the alignment of the spit as a whole. Field observations of berm heights and beach cusp dimensions by Davies (1958) support the wave orthogonal diagrams, and suggest that the energy is distributed comparatively evenly over the beach, decreasing slightly towards the east.

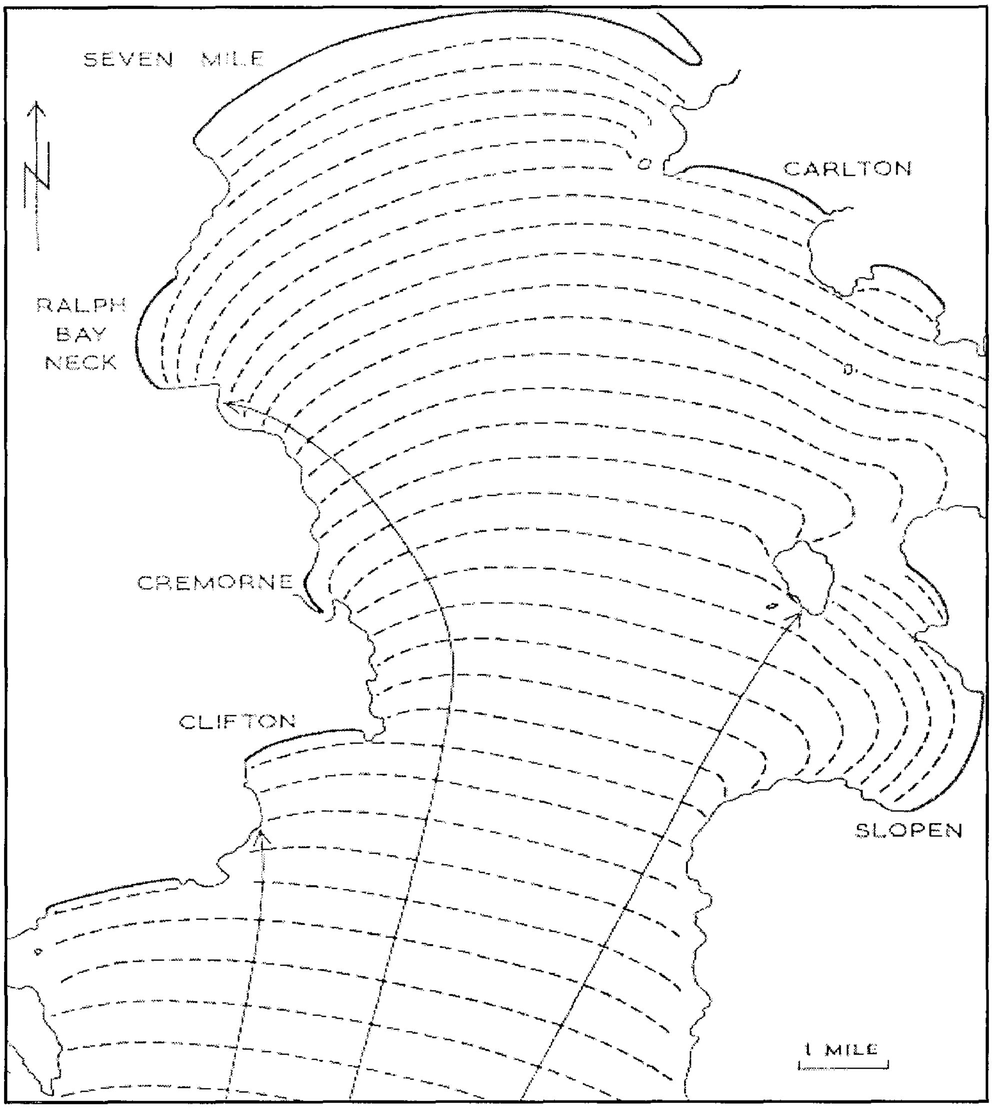


Figure 3.3 - Refraction diagram for Frederick Henry Bay, south east Tasmania. Refraction is for fourteen second south-westerly swell. Sand beaches are indicated by thickened lines, and every fifth wave crest by a broken line. The arrows indicate wave orthogonals drawn equidistant in deep water (After Davies, 1959; Bird, 1968, 1984).

3.2.3 Sources of sediment for the formation of the Seven Mile Beach spit

The quantity of sand contained within the seven-mile long spit at Seven Mile Beach is significant. The question is therefore raised as to the origin or source of the sediment that has accumulated to form the spit at Seven Mile Beach. Geomorphological studies undertaken since the 1950s (Davies, 1959; Hurburgh, 1972), indicate that there is no real evidence to support the idea that a major source of sand has existed in close proximity to the study area, nor are there any rivers entering the sea that could have supplied such large quantities of sediment. Hurburgh (1972) and Chick (pers. com., 1999) state that it seems equally unlikely that erosion of the dolerite or sandstone cliffs in the surrounding area would have yielded much sediment.

Rather than one major source of sediment, it is highly probable that there would have been multiple sediment origins, which combine to contribute to the formation of the spit feature and accumulation of sand at Seven Mile Beach (Chick, pers. com. 1999). Possible sources of sediment include:

1) Reworked sediment from offshore sand bars in Frederick Henry Bay and from the 'older spit' during early stages of formation.
2) Sediment supply to the coast from the continental shelf during the time of the Holocene (post-glacial) marine transgression. This is likely to be the major contributing source of sediment (Thom *et al.*, 1978; 1981).
3) Erosion of soft rock deposits such as periglacial slope deposits and reworking of soils from drowned land.
4) The natural pushing of wave-induced sediment transport (beach and dune material) shorewards (Short and Hesp, 1982).
5) New and reworked carbonate from bio-organisms. This source is a minor contributor of carbonate sediment (approximately 5-6%), providing sediment mainly to the western end of the beach.

Once this material has been delivered to the shore, aeolian processes then act to redistribute the sediments and transport them further to create various different coastal patterns and landforms. These processes are outlined briefly in the following section.

3.3 AEOLIAN SEDIMENT TRANSPORT PROCESSES

To understand how coastal landforms develop and form, it is important to first understand the nature and complexity of the sediment transport processes that contribute to their formation.

Sand transport by wind occurs through one of three modes (Bagnold, 1941; Greely and Iversen, 1985; Sherman and Hotta, 1990; Pethick, 1992): by saltation, by creep and by suspension (in order of importance, according to Goldsmith, 1978, Figure 3.4). Knowledge of sediment transport processes comes from various early studies, experiments and field observations (Bagnold, 1954; Johnson and Kadib, 1965; Kadib, 1965).

Pethick (1992) describes saltation as the process whereby the impact of colliding grains (smaller grains with larger immobile grains) causes the smaller grains to be flicked into the air, vertically upwards, thus triggering the most important process in the movement of grains – saltation (as seen in Figure 3.4). Such a process is initiated in air only, because a sand grain is two thousand times heavier than a similar volume of air, causing the grains to become extremely bouncy.

Bed forms of all scales, from the scale of centimetres to kilometres and tiny ripples to extensive dune fields, are due to saltation processes (Greeley and Iversen, 1985). Sediment transport begins when the shear velocity exceeds the threshold for motion, and individual grains will begin motion when the shear stress (the force that the wind exerts on the sand surface) exceeds a threshold value (Sherman and Hotta, 1990).

Particles move in suspension if they are less than 60 μm in diameter, by saltation (mostly sand sized particles, 60-200 μm), and by creep or traction if the diameter is larger. Pethick (1992) states that grains up to six times the diameter of saltating grains, can move forward along the surface by the process of rolling, sliding or pushing. The amount of sand moved in this way is relatively small, but still significant (Pethick, 1992) and accounts for only one quarter of the total sand in motion. The bulk of sand in motion (three quarters) is moved by saltation, which is why the saltation process represents the most significant component of aeolian sand transport (Bagnold, 1941; Chiu, (no date); Sherman and Hotta, 1990; Pethick, 1992; Mowling, 1997).

The analogy of a group of balls bouncing on a hard surface has been used to describe the movement of sand grains in the air (Pethick, 1992). As the grains become transported higher into the air they pass into increasingly fast wind velocities, which causes them to 'shoot forwards', accelerating them until they are in equilibrium with the velocity of the wind at that height. At the same time, the grains begin to fall back to the beach surface, impacting on grains from the beach and causing them to be projected into the air. Thus the process of saltation continues until the whole beach surface downwind of the original rolling grains is in movement, as can be observed in Figure 3.4. Where grains rise to up to 1 metre above the surface, the beach outline becomes blurred. This is the saltation process responsible for the formation of dunes (Pethick, 1992).

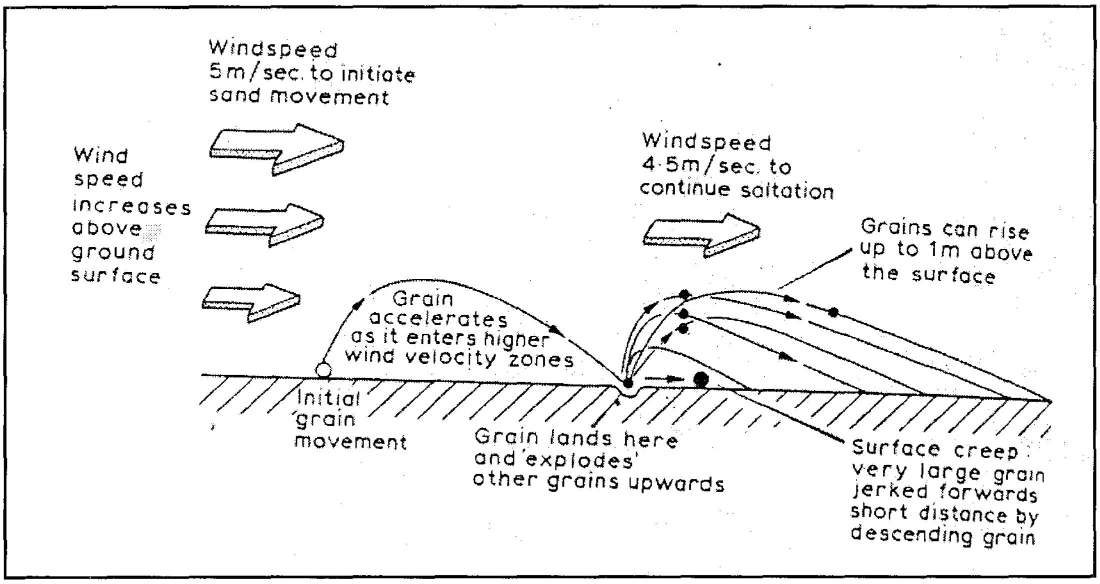


Figure 3.4 - The process of saltation and aeolian transport of sand grains (after Pethick, 1992; Greeley and Iversen, 1985).

Once the various coastal processes outlined above have delivered sand to Seven Mile Beach, its distribution is then altered as a result of aeolian processes and surface roughness factors including vegetation. These processes have led to the development of a series of coastal dune forms and patterns. The following section provides a brief outline of the macro and micro scale bedform features that may develop as a result of the process of aeolian sediment transport, and also describes the major dune features present on the Seven Mile Beach Spit.

3.4 MORPHOLOGICAL FEATURES OF THE SEVEN MILE BEACH SPIT

The Spit at Seven Mile Beach is composed of a complex mosaic of land system patterns and morphological features, that have formed as a result of the interplay of several climatic, tidal and geomorphological factors during the past 12,000 years.

The spit itself forms a land system of its own, classified by Davies (1988) as an 'extensive sand spit,' formed from deposits of recent calcareous sands and dune deposits (as described in section 2.4). Within this broad classification of a 'spit' given by Davies (that applies to the whole of Tasmania), there are a number of smaller dynamic systems that contribute to the morphology of the Seven Mile Beach spit, and these can be identified separately.

Such systems and landform patterns have been documented by Davies (1959) Bradbury (1993), and Dixon (1995), and include macro and micro scale bedform features (as defined below in sections 3.4.1 and 3.4.2) that are predominantly covered and stabilised by exotic vegetation dominated by *Ammophila arenaria* (marram grass) and *Pinus radiata* (Morterey Pine). Some of the larger scale features remain active systems where vegetation has not been able to establish, including a twelve metre high extensive sand dune ridge near the end of the spit at Sandy Point. The area also contains a number of intermittent or seasonal wetland sites that fill with water after periods of heavy rain. An analysis of the present land systems which extend over the south-eastern end of the spit is covered in more detail in Chapter 4.

3.4.1 Macro scale bedform features

Macro scale bedform features are those forms or patterns that can be identified or distinguished on aerial photography taken from altitudes up to 43,000 feet (Mowling, 1998). Macro scale features include transgressive dunes, transverse dunes and deflation surfaces (erosional features) such as blowouts and slacks.

The present spit is composed of a series of between 40-50 sand beach ridges, that are several metres high and orientated parallel to the present shoreline (Davies, 1959; de Gryse, 1996). It is understood that the beach ridges possibly formed during the Holocene, and ceased formation several thousand years ago when the sediment supply diminished. The beach ridges and frontal dunes show a gradual transition in profile from the calcareous sands of the present day to the incipient podzols of the Holocene (Davies, 1959; Goede, pers. comm., 1999).

Several other macro scale land form features, including transverse dune ridges, sub-parallel beach ridges, and windblown sand sheets (previously mentioned in section

2.5), have been documented as being significant in terms of geodiversity conservation. Such features have been preserved from the last Quaternary glacial period, and more recently in the Holocene period.

3.4.2 Micro scale bedform features

Micro scale features are those features that are not easily recognised on aerial photographs, although they may be distinguished upon field verification (Mowling, 1998). Such features can be both erosional or depositional and include small accretion bedforms such as shadow or lee dunes, ripples and remnant knolls, and small deflation surfaces and hollows. Within the Seven Mile Beach spit system, a significant micro-scale bedform feature is the shadow dune, that predominantly occurs behind clumps of dune grasses.

Shadow dunes (or lee dunes) are depositional features, formed as a result of wind acting predominantly in one direction for a period of time (Hesp, 1981; Heyligers, 1985; Greely, 1986). Airflow is diverted around an obstruction to form a 'horseshoe vortex', depositing sand on the lee side of obstacles such as boulders, vegetation or other topographic features. However, Pethick (1994) states that only where there is vegetation can a 'true' dune develop. Shadow dunes have a characteristic pyramidal or linear shape with a sharp-edged crest, with their size being proportional to the size of the obstacle (Tsoar, 1989; Hesp, 1981) as demonstrated in Figure 3.5. Hesp (1981) found that the width of the obstacle and the angle of repose of the sand grain are important in determining the height of the shadow dune.

The presence of vegetation over most of the Seven Mile Beach Spit area undoubtedly influences the way in which sediment is transported across the region, and also contributes significantly to the morphological features present.

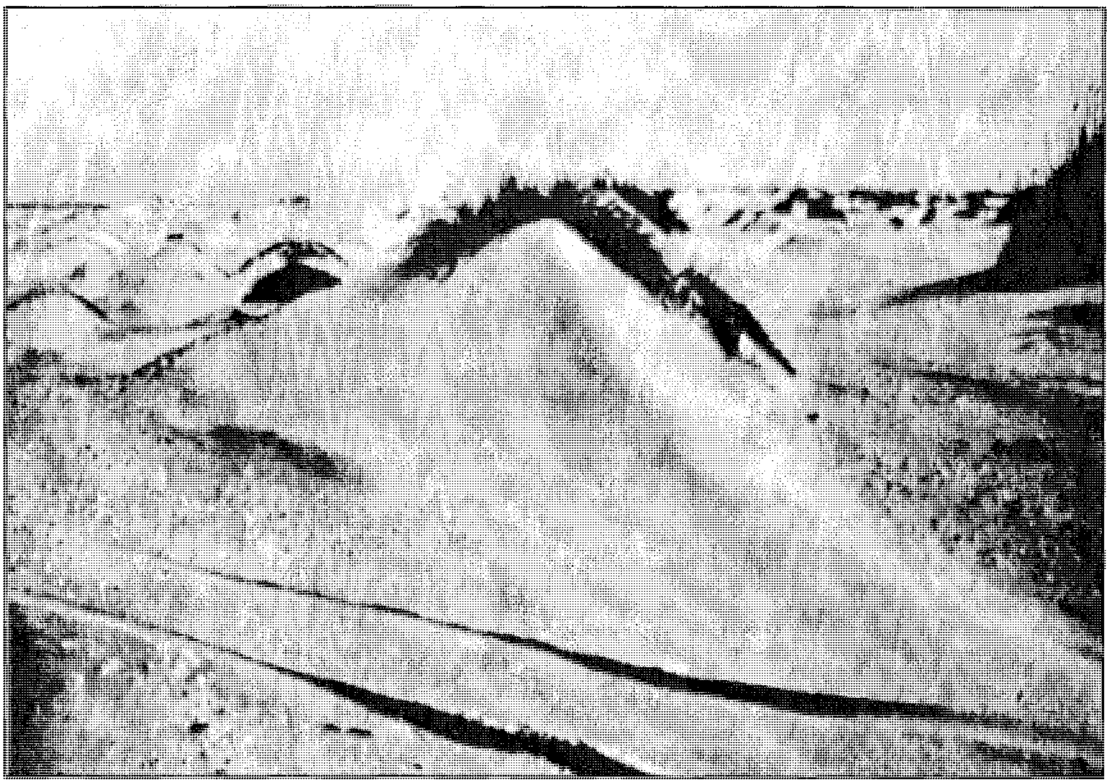


Figure 3.5 - Formation of a shadow dune behind vegetation. Note the pyramidal, linear shape with a sharp-edged crest which is formed behind the obstacle in the direction of the prevailing wind (after Goldsmith, 1978).

The following section details the effects of vegetation on dune morphology and sediment transport by wind. The effects of different vegetation types on dune morphology will also be discussed.

3.5 INFLUENCE OF VEGETATION OF DUNE MORPHOLOGY AND SEDIMENT TRANSPORT BY WIND

3.5.1 Effects on wind velocity and surface roughness

In all but the most arid dune regions, plants help trap blowing sand. Through the dissipation of the energy of the sand-burdened wind, vegetation forces the wind to drop part of its load (Olson, 1958). Bell (1988, p.3) states that 'without vegetation, the upper beach would be largely flat and uniform'. According to Tsoar (1989), vegetation, as an element of surface roughness, generally decreases the impact of wind on sand. Different attributes of plant cover such as density, shape, height and community composition, all influence aeolian sediment movement on dunes (Olson, 1958; Bressolier and Thomas, 1977; Hesp, 1981; Tsoar, 1989). As vegetation is not a solid obstacle to sand-moving winds, sand is able to penetrate through the vegetation and become trapped within the vegetation (Goldin, 1980; Tsoar, 1989). Boorman (1977), Hesp (1981) and Tsoar (1989) describe how the 'airflow streamlining effect' of clumped plants such as grasses, can induce sand deposition in the leeside hollow of reduced wind velocity. As flow is diverted around the front of the plant, acceleration occurs on the immediate sides of the plant, forming a wake in the lee (Hesp, 1981, Figure 3.6).

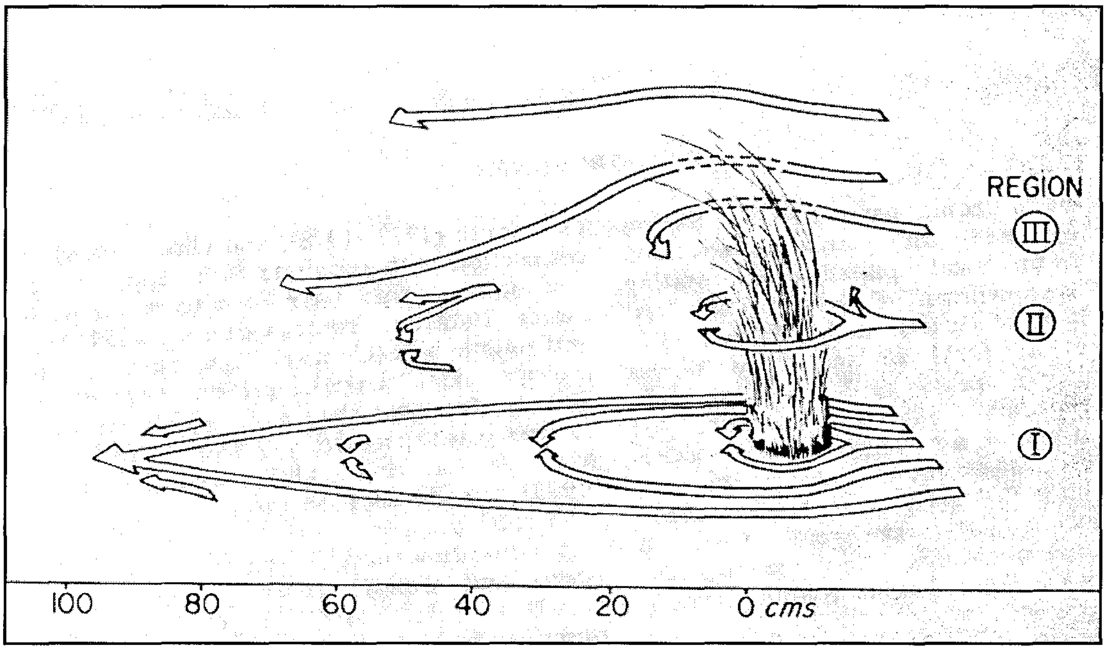


Figure 3.6 - Air flow past an *Ammophila* or *Festuca* plant - derived from wind tunnel experiments, looking at smoke plume behaviour and sand grain movement (after Hesp, 1981).

Heathcote (1983) has found that grasses mitigate more effectively against aeolian entrainment than trees and shrubs, due to most wind-transported sand (90 per cent) being carried in the lowest 0.5 m of the atmosphere. The effects of vegetation on dune formation and hence surface roughness has been documented by Sherman and Hotta (1990), who state that the first shoreward encounter of wind and vegetation causes an abrupt gradient in surface shear stress that results in moving sand being deposited quickly.

Plant shape has also been found to contribute to the nature of airflow modification by vegetation. Wind velocities may be enhanced as airflow is streamlined around clumped grasses, promoting aeolian scour and an increase in sand transport around the sides of plant obstacles (Tsoar, 1989). Hesp (1983) states that the canopy of vegetation is penetrated more easily with increasing wind velocity (especially during gusts). Futhermore, with increasing wind velocity, the vegetation is forced closer to the ground and roughness lengths are lowered (Thom, 1971; 1972).

The effects of vegetation on surface roughness have been documented by Goldsmith (1978), who found that the presence of vegetation creates an increase in surface roughness. He also noted that the effects of vegetation are active not only close to the surface, but at heights of metres above the surface as well. Experiments conducted by Olson (1958) in Indiana, have shown that the planting of grasses on previously bare surfaces, dramatically increased surface roughness. He found that after two years, the dune surface had changed from erosional to accretional, with 2 vertical feet (~60 cm) of sand accumulation occurring around the grass.

3.5.2 Effects of different vegetation types on dune shape and form

According to Dieckhoff (1992) vegetation (particularly dune grasses) plays a vital role in all stages of dune formation. The grass helps to stabilise the sand surface, to reduce and change or modify the effect of wind, and to trap sand, which encourages further dune growth.

A number of authors (Heyligers, 1985; Bell, 1988; Dieckhoff, 1992) have noted that different types of vegetation are responsible for contributing to different dune forms. The morphology of plant-induced dunes is dependant on a number of factors such as the characteristics of the vegetation involved, and also the wind regime and the sediment availability (Bagnold, 1953; Hesp, 1981; Pye, 1983; Heyligers, 1985; Thomas and Tsoar, 1992). For example, Sarre (1989) in his study of coastal dunes has found that the pattern of erosion and accretion over a foredune is controlled by the vegetation cover, and that the height of dunes influences the sand movement pattern.

Similarly, Heyligers (1985) emphasises the direct link between the growth of a dune plant (particularly the growth-habit of the plant) and the expansion of the dune. He also states that the shape of the shadow dune is a result of the plant type (or species) behind which it has formed. For example, plants that are low and horizontally spreading (such as the native grass *Spinifex sericeus*) generally build low wide dunes, whereas tussock grasses such as the introduced marram grass (*Ammophila arenaria*), and more upright bushy plants tend to construct isolated high dunes (Bell, 1988). These patterns are demonstrated in Figure 3.7.

The effect of introduced plants on coastal dunes has been well documented by Hesp (1981), Heyligers (1985), Wiedemann (1987; 1988); Bell (1988); Pemberton and Cullen (1997a); Hertling (1997) and Cullen (1998). Species such as *Ammophila arenaria* (marram grass) have out-competed many Australian native species as they grow faster and can trap sand at a faster rate, thereby creating much larger, steeper dunes (Pemberton and Cullen, 1997a). Heyligers, (1985) has studied the growth habits of numerous foredune plant species (both indigenous and introduced). He has noted that many dune species perform only a secondary role in dune building, either because they are not abundant enough to dominate a dune alone, or because they play more of a stabilising role than a dune building role.

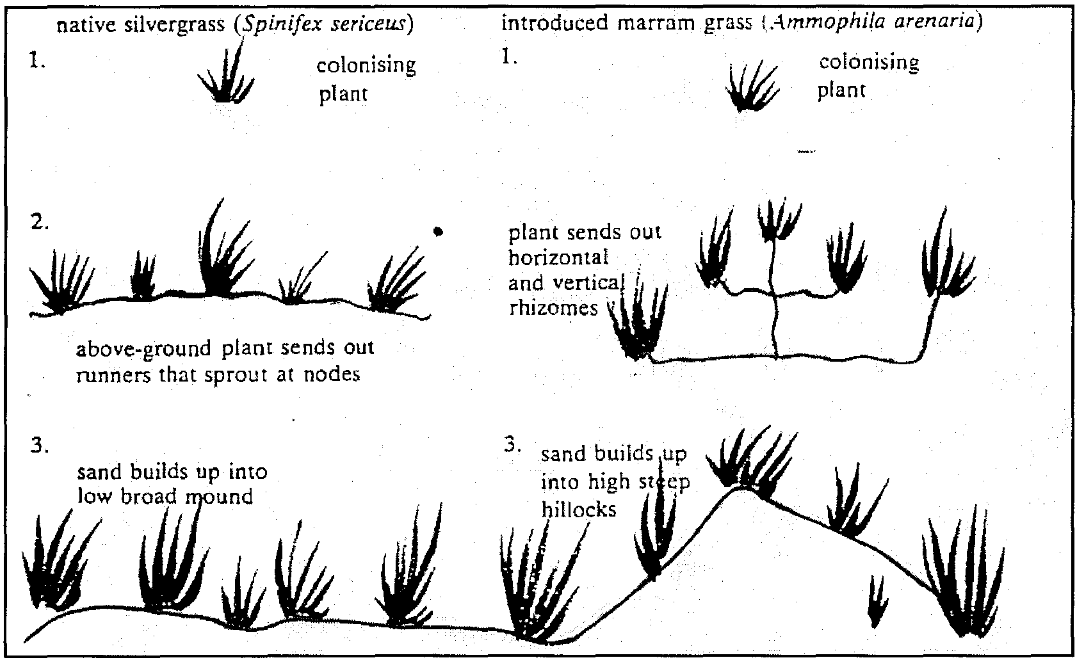


Figure 3.7 - Comparison of different plant types (native and exotic) and their effects on foredune formation. The native silvergrass (*Spinifex sericeus*) is a low horizontally spreading plant, which builds generally low wide dunes. The introduced marram grass (*Ammophila arenaria*) is a tussock grass, and tends to construct isolated high dunes. Both species are good at trapping wind-blown sand, however the native plant spreads only horizontally, whereas its introduced counterpart extends vertically as well (after Bell, 1988).

In this context, several of the more aggressive introduced colonisers such as marram grass (*Ammohpila arenaria*), European sea rocket (*Cackile maritima*), sea spurge (*Euphorbia paralias)* and sea wheat-grass (*Elymus farctus*), are of particular concern for their effects on Australian coastal foredunes. Heyligers (1985) states that around one quarter of all the plants species occupying foredunes in south-eastern Australia are exotics, and it is becoming rare to find a section of coast where only native vegetation occupies dunes. Bowden and Kirkpatrick (1974) also observed that *Ammophila arenaria* has almost totally displaced the native sand binder *Austrofestuca littoralis*, in some coastal areas in Australia.

Although an aggressive exotic coloniser of the upper beach environment, European sea rocket (*Cackile maritima*) maintains similar dune shapes to that of its native competitor, dune fescue (*Austrofestuca littoralis*). This cannot be said for other introduced grasses such as marram grass (*Ammophila arenaria)* which has invaded at a rapid rate, impacting significantly upon the Australian coast. The effects of marram grass on foredunes and movement of sand in the near shore-beach-foredune zone, on many beaches of south-eastern Australia has been well documented (Pemberton and Cullen, 1997).

There has been an increasing realisation of the impacts that invasive introduced species such as marram grass are having on coastal landforms and ecosystems world wide (Kirkpatrick and Harris, 1995, Wiedemann and Pickart, 1996, Cullen, 1998). It is for this reason that marram grass was chosen as part of the focus of this study.

Marram grass or European beachgrass, a native species of Europe and the Mediterranean area (Carolin and Clarke, 1991; Wiedemann, 1988), has been introduced to many other coastal areas across the world in order to combat dune erosion (Jones, 1997). Marram grass is extremely well adapted to a cool temperate maritime climate, and therefore thrives along the coasts of south-eastern Australia, South Africa and northern and western America (Lubke *et al.,* 1995; Pemberton and Cullen, 1997). The grass was introduced in to Australia in 1883 for sand stabilisation purposes at Port Fairy, and since this time has been used extensively for dune stabilisation purposes on many south-east Australian beaches.

Marram grass is a dense tussocky grass, which grows up to heights of 1 m (refer to Plate 3.1). Branched, vertical, underground stems are a characteristic of the grass, and grow both vertically and horizontally (Carolin and Clarke, 1991; Jones, 1997; Haber, 1998).

Plate 3.1 - Marram grass (*Ammophila arenaria*) a native dune binding species from Europe and the Mediterranean area, and a rapidly colonising invasive species in many coastal areas of the world. Its dense tussocky structure and ability to send shoots horizontally and vertically make it an excellent sand binding plant (after Carolin and Clarke, 1991).

Flowering and the production of new shoots and roots is stimulated upon burial by sand. Stems shoot upwards, thereby generating large sand hummocks (Haber, 1998). Marram grass has been described by several authors (Lubke, Hertling and Avis, 1995; Jones, 1997; Hertling, 1997) as being an 'aggressive coloniser' of beach areas, forming a dense mat of grass and rhizomes and often displacing native species. According to Bell (1988) a single individual of marram grass can build up a steep sided knoll in excess of 5 metres high (Plate 3.2). Marram grass achieves dominance through the production of great numbers of vertical tillers and culms, resulting in heavy foliage cover, with 100% ground cover occupation in the long term (Wiedemann, pers. comm., 1999).

Plate 3.2 - Steep sided knolls created by marram grass (*Ammophila arenaria*) along the north-east coast of Tasmania. Due to marram's rapidly growing rhizomes and dense tussocks that it produces, it can continue to raise a dune at rates of up to 1 metre per year.

Marram grass has been particularly successful in invading many of the coastal regions of south-east Australia, owing to the following characteristics:

- rapid colonisation;
- rapid vertical growth;
- vegetative reproduction;
- out-competes and displaces native vegetation;
- is the most aggressive of the common introduced beach colonisers;
  very efficient at trapping sand;

As a result of the above characteristics, it creates the following impacts on coastal dune environments:

- builds dunes which are steeper than the natural angle of repose of sand consistently >30^0 (Bagnold, 1941);
- changes nearshore-shoreface-dune dynamics by interrupting the supply of sand both inland and to the surf zone;
- builds stable dunes on naturally bare areas such as blowouts or ephemeral sand spits and tombolos; results in alien dune forms;
- can impede longshore drift resulting in changes to beach-barrier systems in adjacent embayments; and
- provides and/or creates unfavourable habitats for nesting shoreline bird species (Cullen, 1998).

The characteristics and impacts described above, make marram grass a serious threat to many coastal areas around Australia, particularly to areas where the native vegetation remains relatively intact, and where the dune systems are unaltered by introduced species (Cullen, 1998).

Marram grass was introduced in to Tasmania in the late 1800s, by farmers in an attempt to try and stabilise encroaching sand dunes in the north-east of the state (Steane, pers. com. 1999). During the period between the 1950s to the mid 1990s, large areas of coastal dunes and extensive trangressive dune fields were intensively planted with the species in the north-west, the north-east and the south-east of the state (Cullen, 1998). Consequently, marram grass has come to be the dominant dune species at many locations, with its range extending to well over half the Tasmanian coastline (Cullen, 1998).

It is only recently that *Ammophila arenaria* has been found to have spread beyond areas where it had been purposefully introduced. Studies undertaken by Cullen (1998), along the south-west and west coasts of the state, reveal that marram grass has invaded sections of the coast, occurring up to 100 km away from the nearest known planting of the species (at Ocean Beach, Strahan). Prior to this study, a large section of the south-west and south coasts was considered to still be in natural condition, and free of any invasions by the species.

A situation similar to that of the south-west and south coasts exists along the Seven Mile Beach Spit. Marram grass was introduced to the foredunes of Seven Mile Beach in the early 1900s to try and stabilise the foredunes. Since the species was planted along Seven Mile Beach, it has progressively invaded further east along the coast, following the direction of the prevailing currents and longshore drift. The extensive bare dunes located at Sandy Point (at the end of the Seven Mile Beach Spit), have been invaded by *Ammophila arenaria* progressively since the late 1940s, (as evident in aerial photographs taken of the area, detailed Chapter 4). The area of bare dunes (and several other land cover types) present at Sandy Point, has been greatly diminished as a result of the invasion of marram grass. Demonstrable evidence to support this is presented and discussed further in Chapter 4.

3.5 CHAPTER SUMMARY

The morphology of spits and other coastal dune features reflects the interaction of waves, longshore drift currents and aeolian sediment transport dynamics. Within the Seven Mile Beach Spit system a number of distinctive morphological features exist, many of which are a result of aeolian sediment transport processes and the influence of vegetation that covers much of the area.

A dynamic equilibrium must exist between form and process, in order for landform features to become stable or to continue to form. The introduction of several exotic species (particularly marram grass) to the spit area at Seven Mile Beach, has led to a disruption of the balance between form and processes operating. This has resulted in large amounts of sediment being locked up by the highly efficient dune binding species. The effects of marram grass on coastal dune form has been of increasing concern to coastal geomorphologists over the past decade. The main concern is that the grass poses a serious threat to several coastal systems around Tasmania that have not yet been invaded by the plant or are likely to be invaded.

As a result of the invasion of marram grass at Sandy Point, dunes have become oversteepened such that their slopes are greater than the natural angle of repose of sand ($>30^0$). Hummocky dunes and hillocks now dominate the foreshore area of Seven Mile Beach and Sandy Point. The introduced dune species now completely dominates the coastal vegetation of the area, out-competing all but a few native species. In the following chapter, the invasion of marram grass at Sandy Point between 1948 and 1997 is investigated, while in Chapter Five the influence of marram grass on sediment transport dynamics is examined.

CHAPTER 4

CHANGES IN THE MORPHOLOGY AND LAND SYSTEMS OF THE SEVEN MILE BEACH SPIT SINCE 1948

4.1 INTRODUCTION

The purpose of this chapter is to provide an assessment of the changes that have occurred to the morphology and land cover of the Seven Mile Beach spit during the past 50 years 1948. Chapter four presents the methods and approaches that were used to determine the changes occurring to land cover and the shoreline since 1948 (section 4.2). Section 4.3 discusses the reliability of the spatial and attribute data, whilst an analysis of the land cover and shoreline changes are presented in section 4.4. A discussion of the findings and chapter summary is presented in section 4.5 and 4.6 respectively.

Two main objectives are addressed in this component of the study. The first is to map the land cover and shoreline changes at Seven Mile Beach for the years 1948, 1966, 1980 and 1997. The second aim is to determine the change in area to each land cover type, particularly the changes in marram grass and bare sand cover across the area.

Aerial photography combined with GIS has been effectively used by Jungerius and van der Meulen (1992) to monitor blowout development in the Netherlands. GIS has also been used successfully by Walton (1998) to assess rates of shoreline change in Florida, U.S.A. Cooper (1958), has used a combination of aerial photography and field work to examine coastal dune systems and landscapes.

4.2 METHODS

4.2.1. Creating spatial data sets from aerial photographs

Aerial photographs from four different years between 1948 and 1997 were used to compare land cover and shoreline changes occurring on the Seven Mile Beach Spit. Given this spread of approximately 50 years, it was anticipated that variations in shoreline position and land cover could be identified. The photographs ranged in scale from 1: 15,000 to 1: 42,000. Aerial photographic information is presented in Table 4.1.

Registration problems were created due to the variability between scale and flight elevation of photographs taken in different years. Such registration problems have also been noted by Illenberger and Rust (1988). Accommodation of these problems is discussed below in section 4.2.1.1.

Table 4.1 - Aerial photograph details

Year	Scale	Elevation (feet)	Date	Photo type
1948	1:15,000	11,000	17.1.1948	Black and White
1966	1:40,000	13,000	18.2.1966	Black and White
1980	1: 15,000	16,000	10.2 & 9.4. 1980	Black and White
1997	1:42,000	22,500	13.1.1997	Colour

4.2.1.1 Ground Control Points

Before the aerial photographs could be digitised, registration (or ground control) points determined though the use of a Global Positioning System (GPS) were required. A GPS is a satellite-based navigation system, developed by the United States Department of Defence. The reference system is a geocentric datum with its origin at the earth's centre of mass (Mansor, 1998).

A rapid static GPS surveying technique was used for the collection of ground control points. This technique provides accuracy to within a few centimetres, and is particularly useful where many points need to be surveyed that are widely spread across an area. The technique is also versatile and fast, as there is no need to maintain lock on the satellites when moving from one station setup to another (Rizos, 1996).

A total of ten points were surveyed between Carlton, Dodges Ferry, Lewisham and several points on the spit. A vector data set was created from the surveyed coordinates, which was then converted into a shapefile. The coverage was then built for point topology and used to register each aerial photo (which had been previously scanned and imported into Arc/Info). Once each photo had been registered in Arc Info with sufficiently low RMS (root mean square) error (discussed in section 4.3.1), images were then rectified to enable conversion into vector point coverages.

4.2.1.2 Digitising aerial photographs

Each rectified image was digitised using the GIS program Arc/Info. Shorelines and different land cover polygons were digitised for each year. Once polygons had been created, each digitised layer was cleaned and then built for polygon topology. A clip coverage was then generated for each year, to define the boundary of the study area. This allowed the creation of the different land system coverages with a consistent boundary. Figure 4.1 shows a flow chart of the procedures required for creating digital images from aerial photographs.

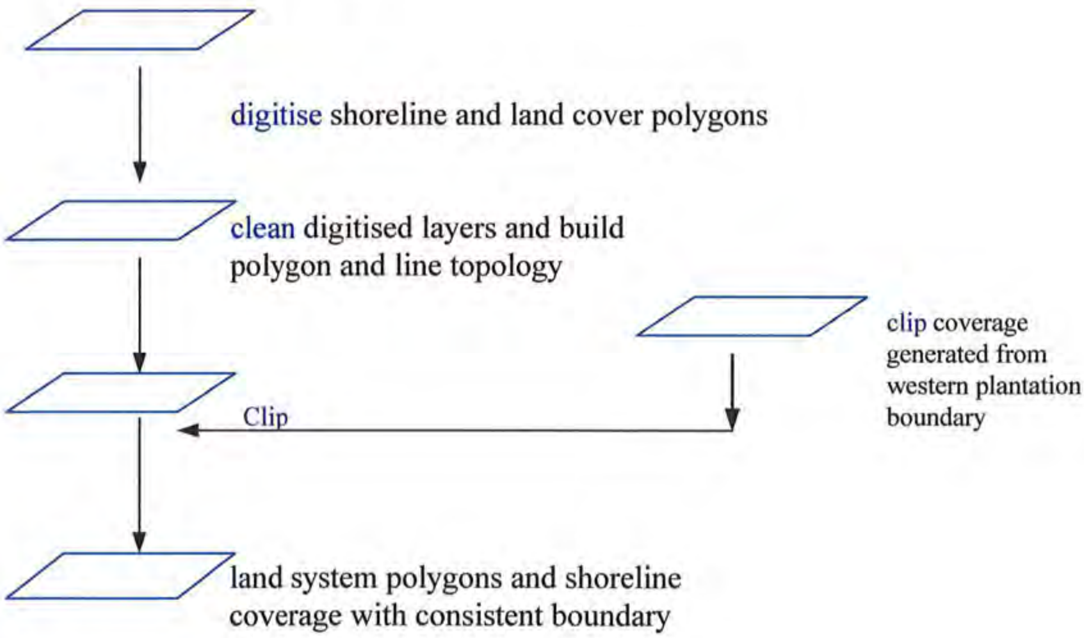


Figure 4.1 - Data capture method for creating land cover and shoreline images for each study year.

4.2.1.3 Analysis of data

Land cover analysis was examined through the creation of different layout and overlay coverages in Arc/View (Figures 4.2-4.5). Data were also exported as attribute tables into Excel, enabling tabular and graphical analysis to be conducted for land cover changes occurring between 1948 and 1997. Total area (ha) was calculated for each land cover type for the four study periods. The data was then represented as a bar chart with columns divided into the seven land cover types that were identified (see Figure 4.6). Land cover types were then split up and examined separately.

The distribution of exotic species (such as *Ammophila arenaria* and *Pinus radiata*) present on the spit was graphed and analysed, focussing on the spread of such species over the spit area between 1948-1997. Layers were created for the entire period of time (~50 years) and then overlayed for selected time intervals: 1948-1966, 1966-1980, and 1980-1997. An overall comparison was also made between 1948-1997.

Shoreline analysis was conducted using a similar approach to that used for land cover analysis. Digitised shorelines for each time interval were buffered, to account for tidal variation error (as the shoreline was taken from the Mean High Water Mark). The shoreline for each year was then overlayed as one image to determine how much movement had occurred during the 50 year study period.

4.3 RELIABILITY OF DATA

4.3.1 Spatial data

Spatial data uncertainty was generated as a result of different levels of registration accuracy, errors created from variations in cell resolution size, and root mean square (RMS) error. RMS error represents the difference between the original control points and the new control point locations calculated by the transformation process (ESRI, 1996). RMS varied between 1.4 m to 4.9 m for the coverages. Cell resolution for the coverages varied between 2.7 m to 7.5 m. Despite some RMS values calculated to 1.4 m, the smallest cell resolution was only 2.7 m, so the resultant coverages were quoted as the maximum of RMS and Resolution for each image (2.7 m to 7.5 m).

Obviously the lower the RMS value, the more accuracy is generated for the final image. However, in some instances, the RMS error was lower than the cell resolution, and therefore became irrelevant, as the maximum degree of error is counted. For the purposes of this study, the RMS errors obtained are considered to be adequate.

4.3.2 Attribute Data

Another contributing factor to data uncertainty was the difficulty in identifying and distinguishing between different land cover types. This partly reflected variability within and between the seasons in which the aerial photos were taken. Ideally, photographs taken during summer and winter could be used to overcome such problems (Cooper, 1958).

As a result of the difficulty in distinguishing between different land cover types, it was therefore also problematic to allocate boundaries to some land cover types, and maintain consistency for each different coverage. This issue was further compounded by poor image quality of some of the photographs (particularly the 1948 photographs, which were extremely washed out), and the presence of highly reflective sand bodies covering the area.

Photographs taken at high flight elevations (22,500 feet) and small scales (1:40,000 and 1:42,000) further contributed to the problems of identifying ground features and distinguishing between different land cover types. The season in which the photographs were taken also potentially affected the amount of vegetation cover that could be identified. For example, during the summer season grasses may become dried and turn yellowish, making them hard to distinguish from areas of reflective bare sand. Distinguishing between native and non-native vegetation also proved difficult in some of the coverages. Mowling (1998) identified similar problems with aerial photograph interpretation.

Through creating overlays of the four different years, further propagation of error arose as a result of the different levels of registration accuracy between the data sets (as mentioned previously in section 4.2.1). Digitising the shoreline of each coverage created further possible errors. Garret (pers. comm., 1999) recommended digitising the Mean High Water Mark, as represented by the top of visibly wet sand that could be seen on each aerial photographic image. Tidal data was obtained from the Hobart Ports Corporation (1999) for each year except 1948. The tidal range of the particular day each photograph was taken was documented. Despite obtaining tidal data for the purpose of digitising the shoreline, it was decided that the shoreline would be digitised from the line of the Mean High Water Mark. The tidal range for each year was however, taken into account for calculating generated error.

A beach slope of 6^0 was assumed (Platt, pers. comm., 1999), as this figure is the standard used for beaches that are generally wide and flat, such as Seven Mile Beach. The calculated tidal error varied for different years. The tidal error for 1948 and 1966 was calculated to be approximately 12 m, and 6.7 m for 1980 and 1997. The total error therefore, was the sum of all calculated errors for each year (i.e. $\sum$max. spatial data error + attribute data error). The calculated figure for error (assuming the highest degree of error for both attribute and spatial data) is 19.5 m for 1948 and 1966 and 14.2 m for 1980 and 1997.

Once the GIS data set was constructed and the sources of error identified, the aims of the chapter could then be addressed. These were to examine changes in both land cover and shoreline position over the time period selected for investigation (1948-1997).

4.4 LAND COVER ANALYSIS

Results from the land cover analysis indicate that there have been dramatic changes in the types of land cover present, and also in the area that each land system occupies, on the eastern end of the Seven Mile Beach Spit. Seven broadly grouped land cover types were identified on the eastern end of the spit, throughout the fifty year study period. The categories of land cover are defined below. It should be noted, however, that not all land cover types are present in each year .

1) Pine plantation – this land system consists of a *Pinus radiata* plantation. The boundary of this area has remained relatively stable over the past 50 years, as it is a managed unit with well maintained roads around the perimeter. The area was planted in the early 1930s, and the trees were last harvested in 1996.

2) Marram grass (*Ammophila arenaria*) – this land cover type consists almost entirely of marram grass, which was planted along Seven Mile Beach in the early 1900s (Steane, pers. comm., 1999) to help stabilise the foredune area. Since this time it has invaded across the entire length of the spit, extending inland and displacing the native vegetation and areas of bare mobile sand.

3) Remnant Native Vegetation – this land cover type is relatively small in comparison to other land cover types mentioned. It is made up of patchy grassy open *Eucalyptus viminalis* forest, which once had a stronghold on Seven Mile Beach, but have since been displaced by the invasion of exotic species such as pines and marram grass.

4) Mixed pine and marram grass – a land cover dominated by pine wildlings and marram grass, that has invaded from the pine plantation on the western boundary of the study area, and from marram grass plantings along the foredunes of Seven Mile Beach respectively.

5) Native grassland – consists of *Poa poiformis and Selliera radicans* and various wetland species of grass such as *Juncus* sp. (Duncan, 1996). The native grassland occurs predominantly in areas that remain wetter, or are intermittent wetland sites after periods of heavy rainfall.

6) Bare mobile sand – comprises an extensive, active sand dune ridge up to heights of 12 m, on the end of the spit at Sandy point. The land cover type only includes areas of bare sand that have no vegetation covering them.

7) Foreshore – defined as the area of beach immediately in front of the foredunes, and extending to the Mean High Water Mark.

The analysis of each different land cover type, demonstrates that between 1948 and 1997 the invasion of marram grass and pine trees across the end of the spit has been dramatic. Maps of the distribution and extent of each land cover type, for the four study years can be seen in Figures 4.2-4.5.

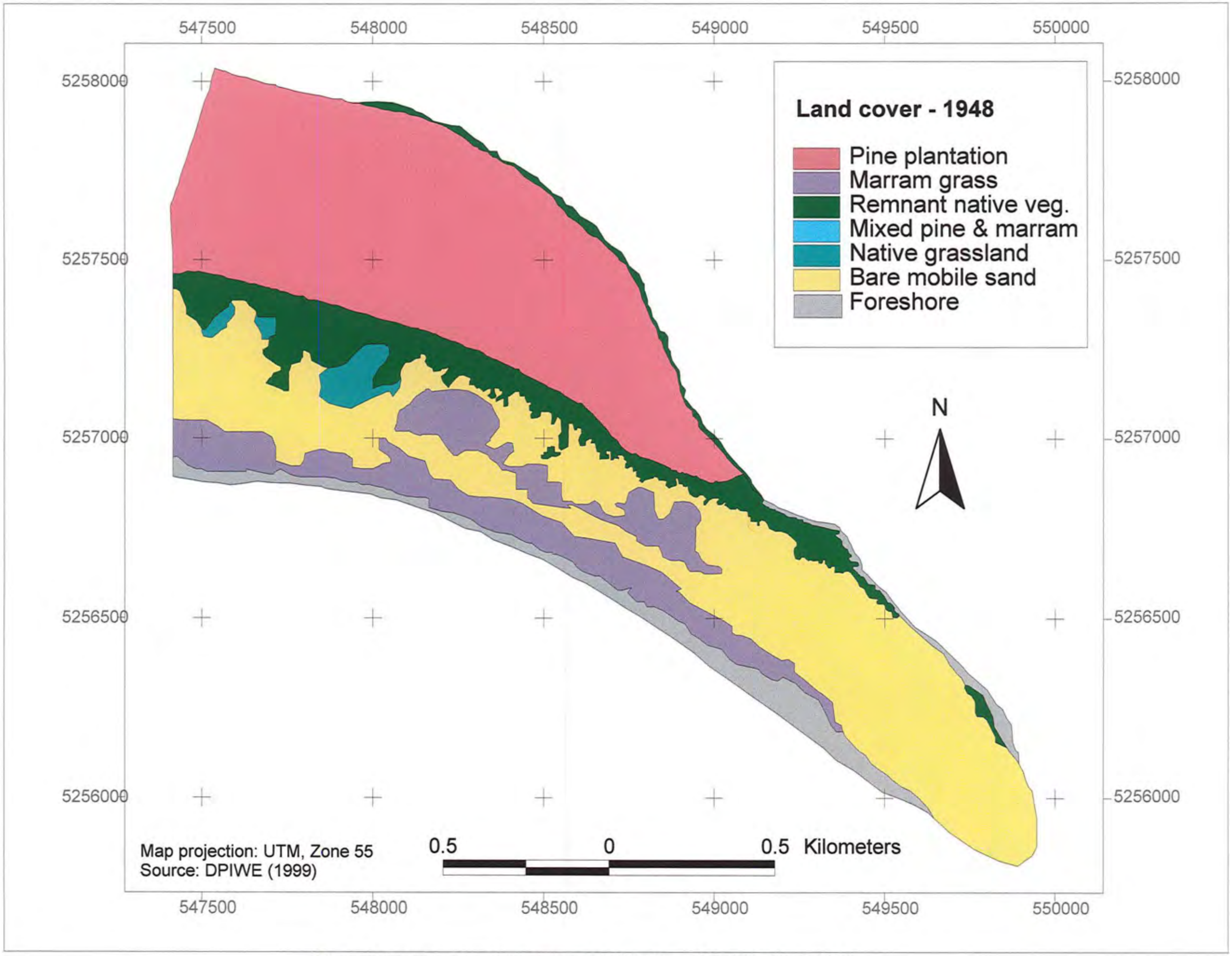


Figure 4.2 - Land cover of the eastern end of the Seven Mile Beach Spit, 1948.

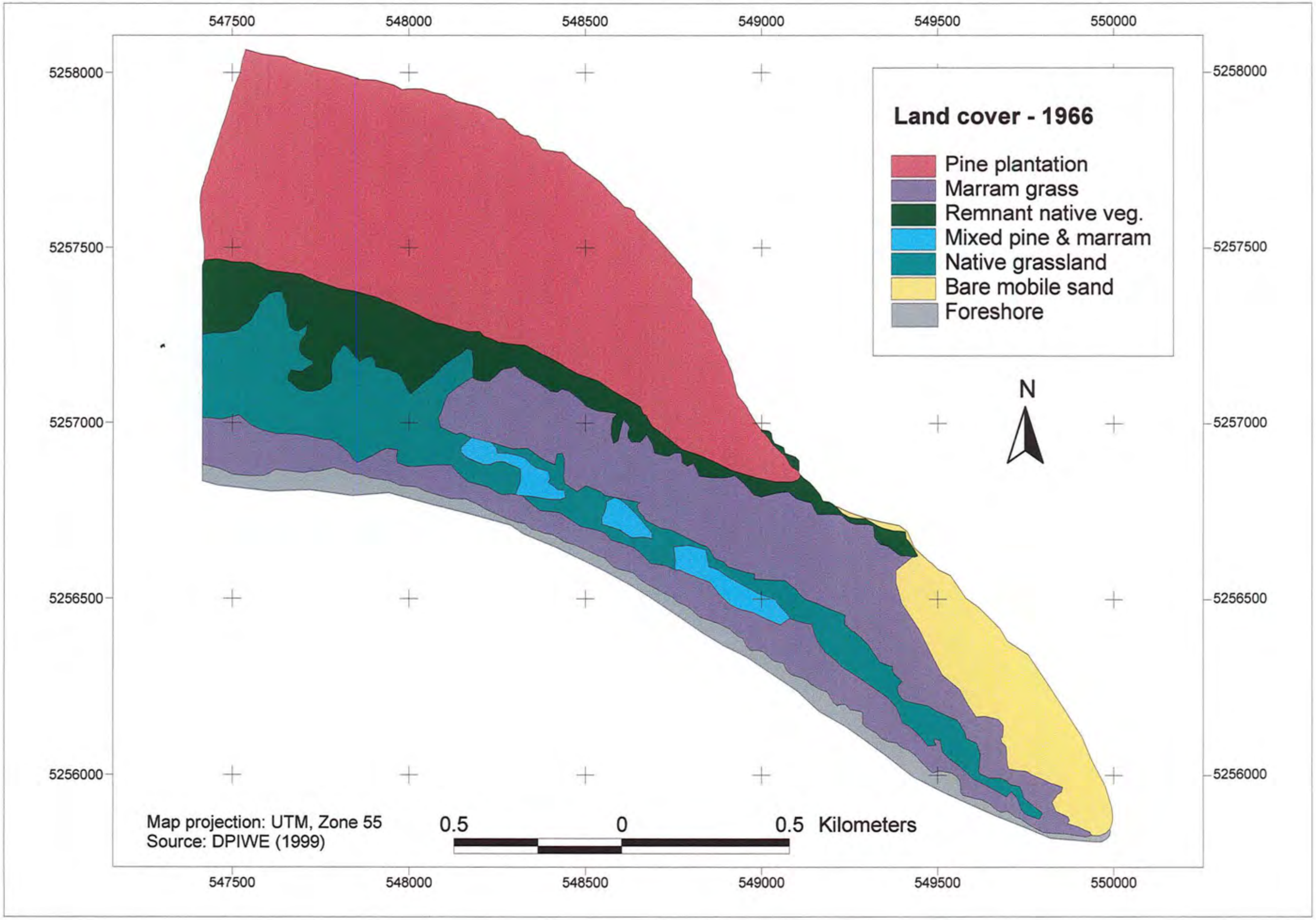


Figure 4.3 - Land cover of the eastern end of the Seven Mile Beach Spit, 1966.

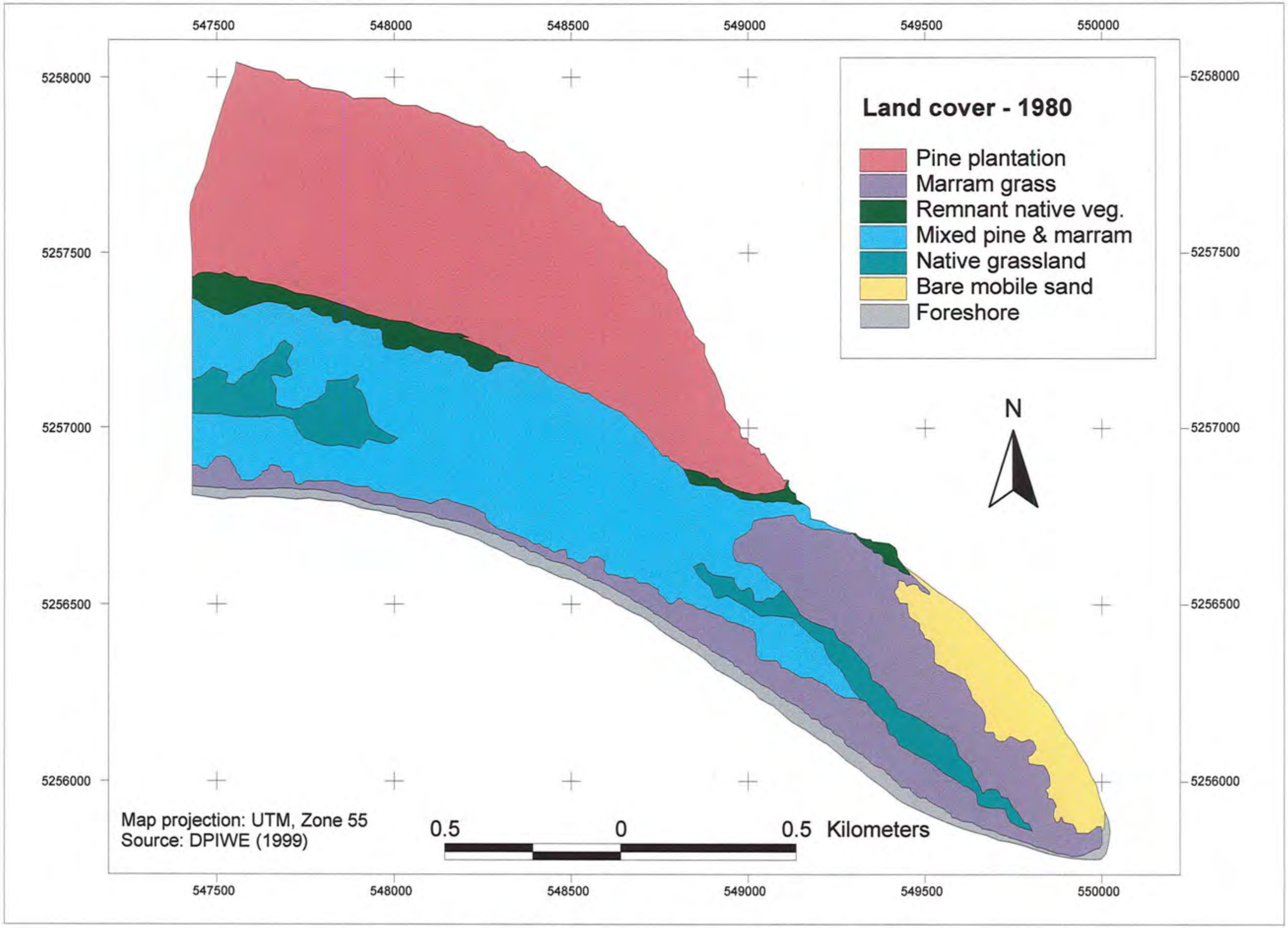


Figure 4.4 - Land cover of the eastern end of Seven Mile Beach Spit, 1980

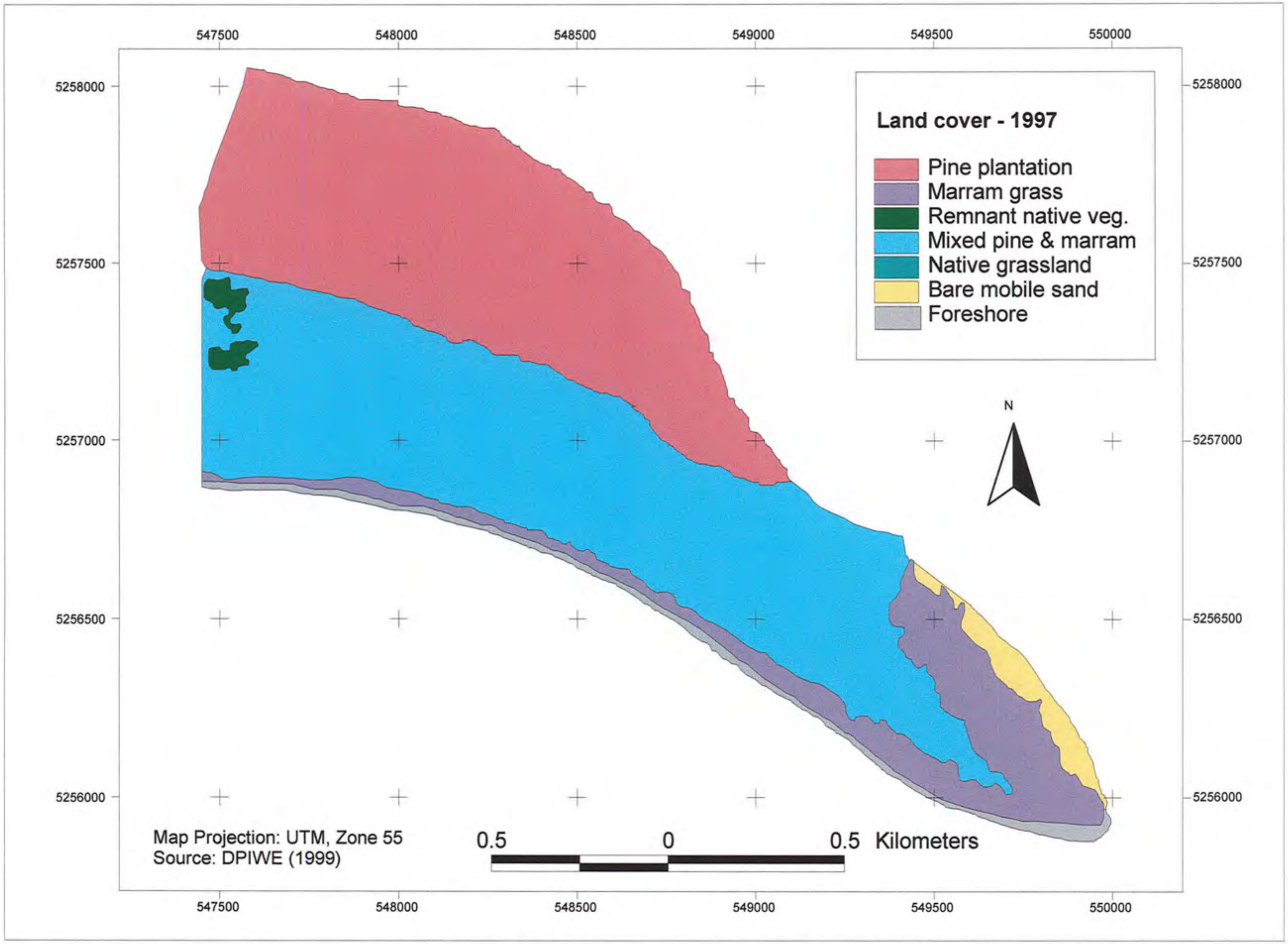


Figure 4.5 - Land cover of the eastern end of the Seven Mile Beach Spit, 1997.

As can be seen in the previous maps, the land cover of the area has changed significantly. In 1948 the area covered by marram grass was < 15 percent of the total area, and by 1997 marram grass combined with pine tree wildlings had increased to cover over 50 percent of the total area. This evidently has had substantial effects on the area of other land cover types present, which have been almost totally displaced by these invasive species. Figure 4.6 presents the changes in area of each land cover type over the period 1948-1997.

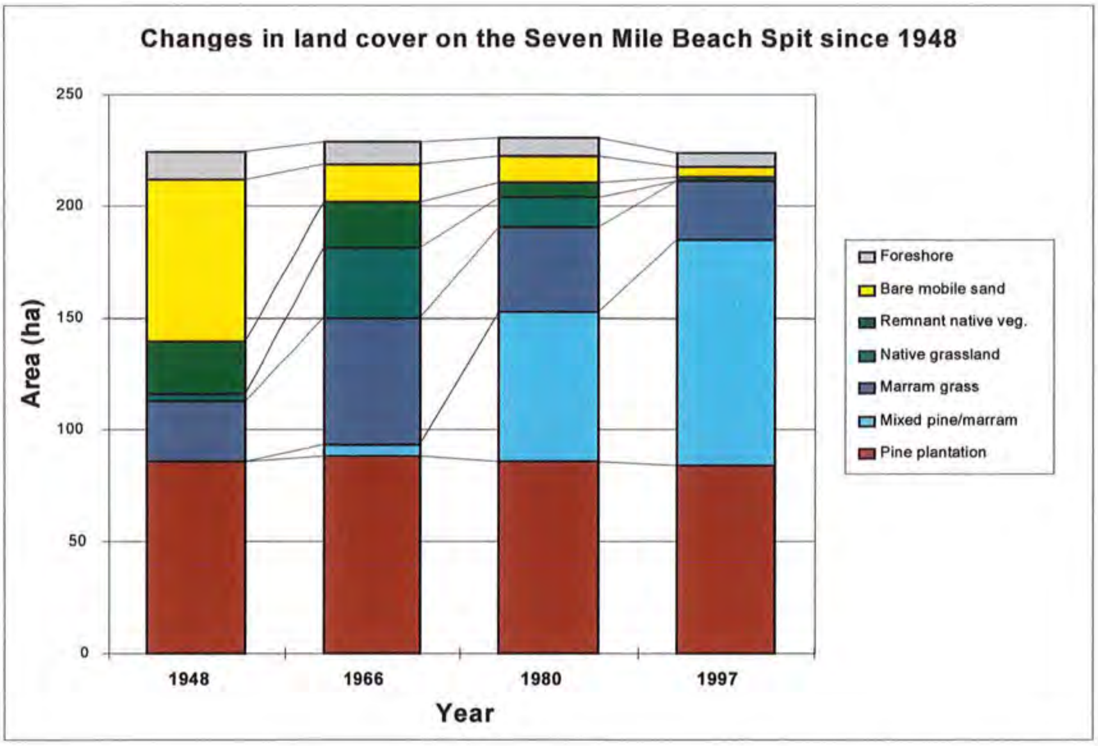


Figure 4.6 - Land cover changes that have occurred on the eastern end of Seven Mile Beach Spit since 1948.

Pine trees (like marram grass) have also spread over a large portion of the spit area, escaping from plantations. In 1948, there were no significant areas of pine wildlings on the eastern end of the spit. The invasion of pine trees and marram grass over the area has contributed to the existence of a predominantly exotic vegetation cover, which is illustrated in Figures 4.7-4.10. As a result of this invasion, the amount of bare mobile sand and native vegetation has also diminished substantially. In 1948 the area of bare sand covered approximately 73 ha, and by 1997 the total area of bare mobile sand has decreased to only 5 ha. However, not all the bare sand has been lost to the spread of exotic species, as some has been lost to the water (i.e. it has been eroded away).

The area of native vegetation cover has diminished substantially over 50 years. Native grassland has almost been entirely depleted since 1948. In 1948 the area of native grassland covered approximately 3 ha, however an increase in area can be seen between 1948 to 1966 where native grassland increased to 31 ha. Between 1966 and 1980 the area of grassland diminished by over half, and by 1997 the area of native grassland had almost disappeared as a result of the spread of marram grass and pine trees over the area.

Remnant native vegetation has also decreased from 24 ha in 1948 to only 2 ha remaining in 1997. Between 1966 and 1980 the area of remnant native vegetation decreased from 21 ha to 7 ha. This coincides with the active invasion of pine tress and marram grass over the area during this time period. Figures 4.7-4.10 show the growing extent and dominance of pine trees and marram grass over the spit area between 1948 and 1997. Note: the other land cover types have been blanked out, to further highlight the dramatic changes that have occurred in land cover on the eastern end of the spit at Seven Mile Beach.

Such vigorous activity is expected with marram grass invasion, as the species is uniquely well adapted to burial by large amounts of sand. Burial is necessary for its vigorous growth and flowering and where burial ceases, often the plant cover becomes reduced and eventually dies (Wiedemann, 1998). It is because of this reason that marram grass thrives in an environment such as on the Seven Mile Beach spit, where it is frequently inundated with sand (especially on the end of the spit). In considering the future changes that may occur to the area of bare sand in relation to marram grass invasion, it can be said that marram grass poses a threat to the bare dune system, and will slowly establish over the dune. Some areas may remain free of the grass as a result of them being too mobile for even marram grass to withstand.

On the coastal dunes of western Europe (where marram grass is native), it does not achieve such dramatic dominance compared to the areas where it has invaded (Wiedemann, 1998). Invasion of this nature is not just occurring at Seven Mile Beach, but to many other beaches in Tasmania, parts of south-east Australia and other parts of the world.

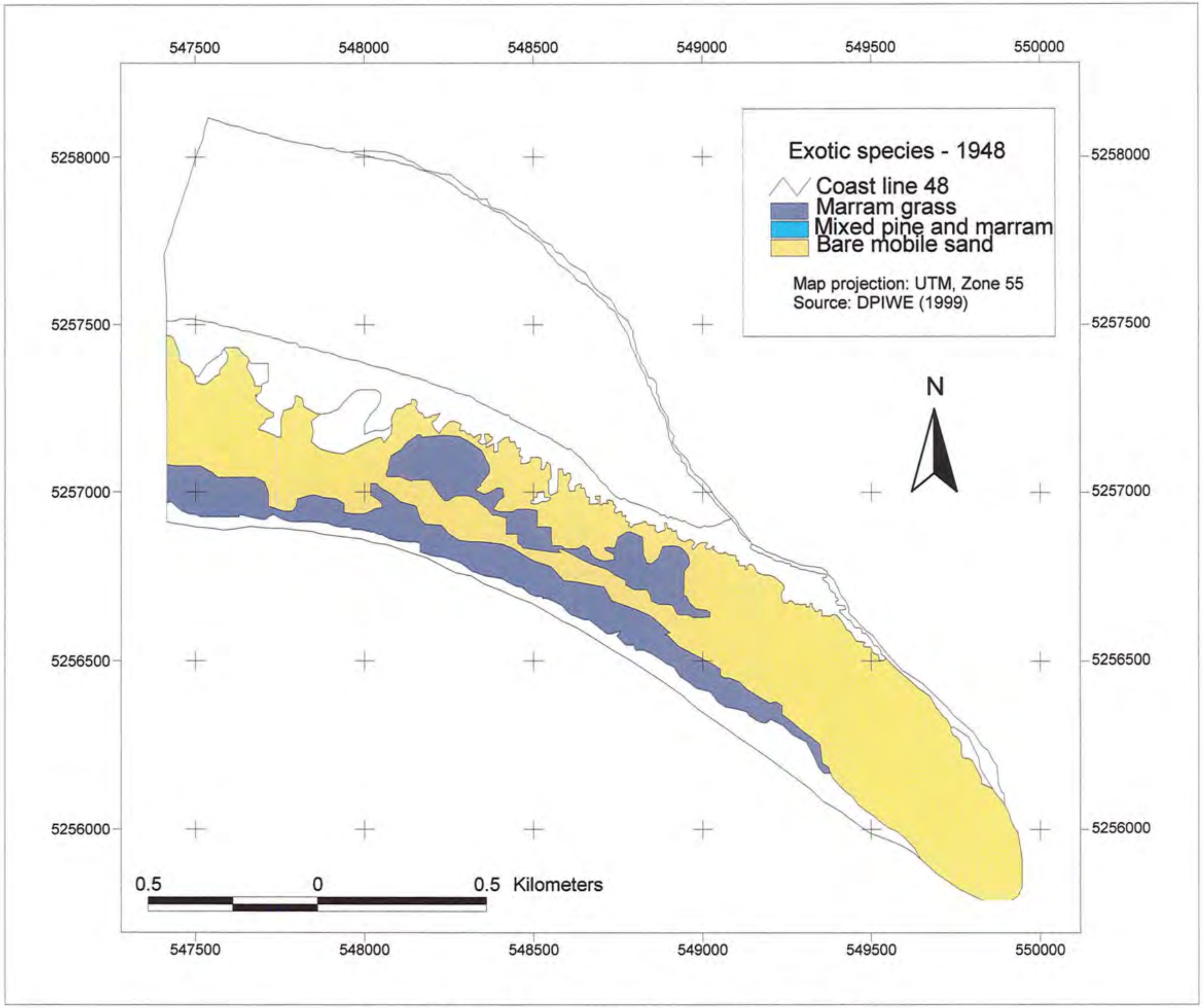


Figure 4.7 - Extent of marram grass, pine trees and bare sand, 1948.

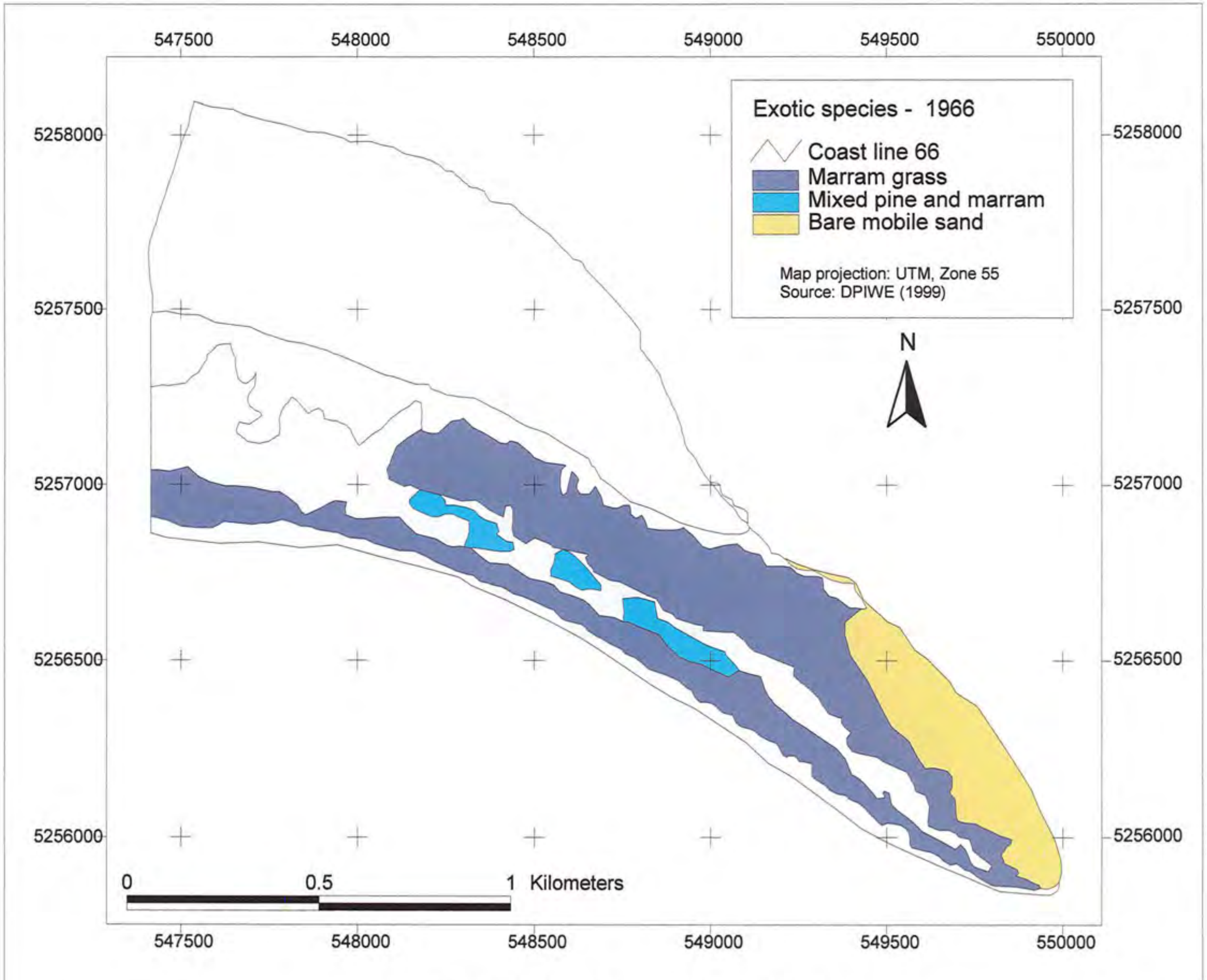


Figure 4.8 - Extent of marram grass, pine trees and bare sand, 1966.

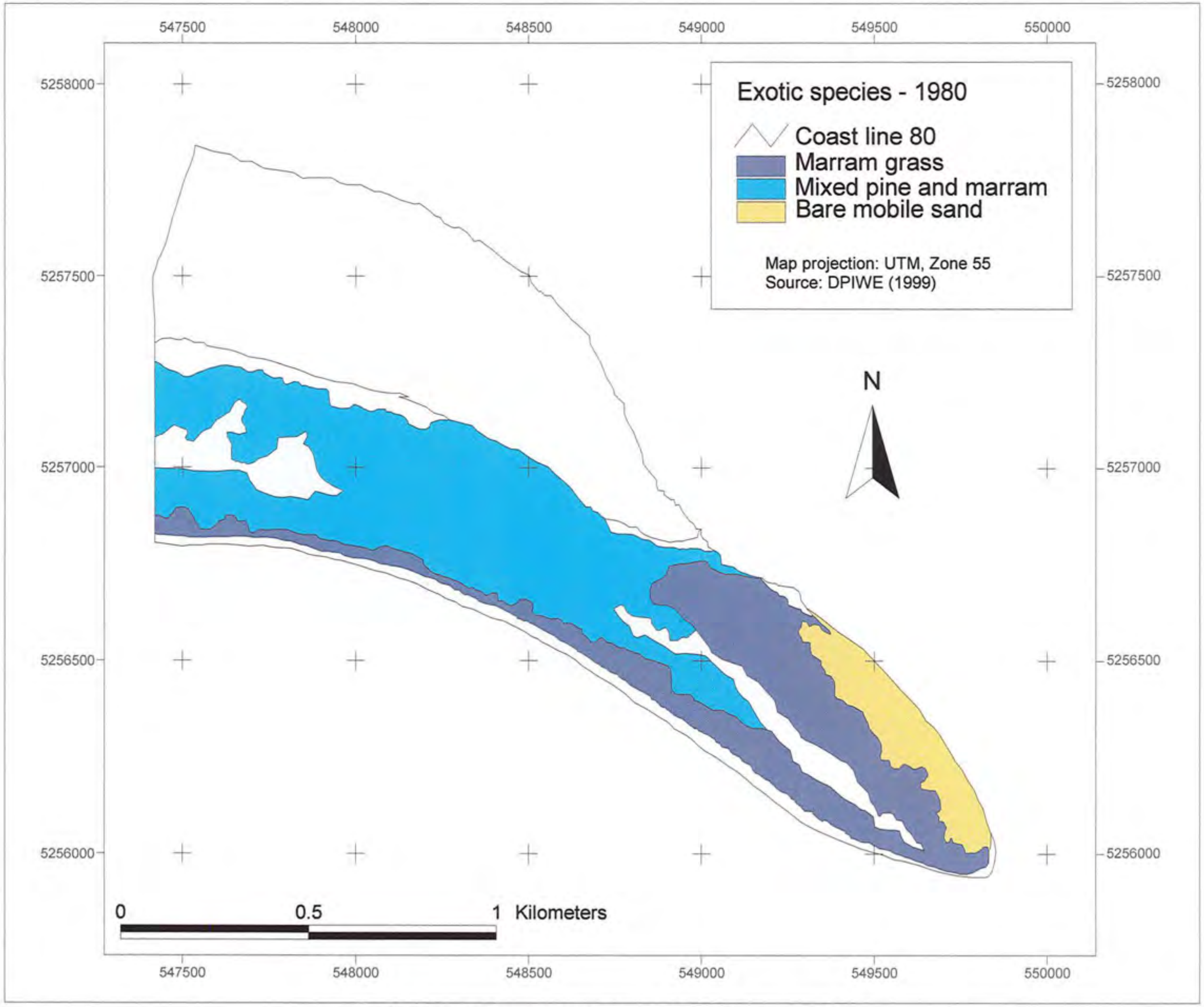


Figure 4.9 - Extent of marram grass, pine trees and bare sand, 1980.

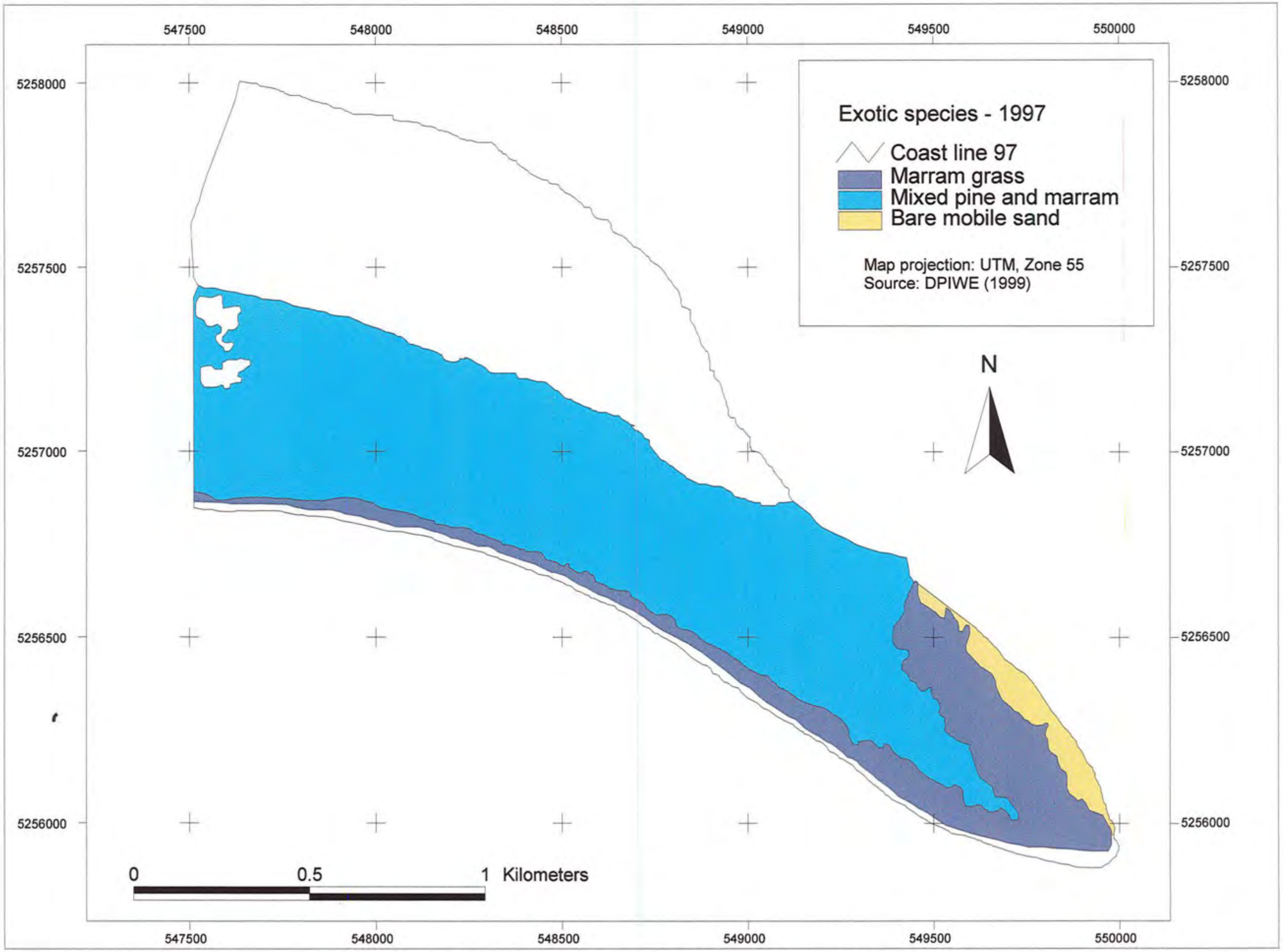


Figure 4.10 - Extent of marram grass, pine trees and bare sand, 1997

4.5 SHORELINE ANALYSIS

Longterm shoreline changes occurring to the eastern end of the Seven Mile Beach Spit were mapped using Arc/Info and Arc/View computer programs, and can be seen in Figures 4.11-4.13. Analysis of the shorelines for each study year has revealed that there have been some substantial changes to the shoreline since 1948. Such changes have also been noted by Dobson and Williams (1977) and Culver (1979), who have previously conducted studies on rates of change of the 'toe' of the spit, which is the are where the most dramatic changes to the shoreline appear to have occurred. Maximum displacement was calculated to be 58 m between 1948 and 1966, with 43 metres displacement between 1980 and 1997. There appeared to be very little change in the shoreline when comparing the years 1966 and 1980.

The buffered shoreline boundary that was created enabled shoreline changes to be seen, that occurred outside the error margin generated. Movement was therefore only deemed significant if it occurred outside the buffered shoreline boundary, that was created to account for error in tidal variation (as discussed previously in section 4.3.2).

Between 1948 and 1966 there was significant movement of the shoreline at Sandy Point. The general trend that can be observed is the migration of the eastern end of the spit further east, into the channel of Pitt Water. Between 1980 and 1997 the shoreline appears to have retreated along the southern side of the spit (Seven Mile Beach). Deposition has occurred along the northern side of the spit between each time period studied. The shoreline on the northern side of the spit where the pine plantation occurs, has remained relatively stable over the past 50 years, as pine trees occur almost up to HWM.

It can also be seen that the area of foreshore is progressively decreasing over time in some areas, particularly along the Seven Mile Beach side of the spit. The rate of migration of the shoreline was found to be episodic, and not constant between all the years (i.e. there was little visible change between 1966 and 1980, but between 1948-1966 and 1980-1997 there were dramatic changes).

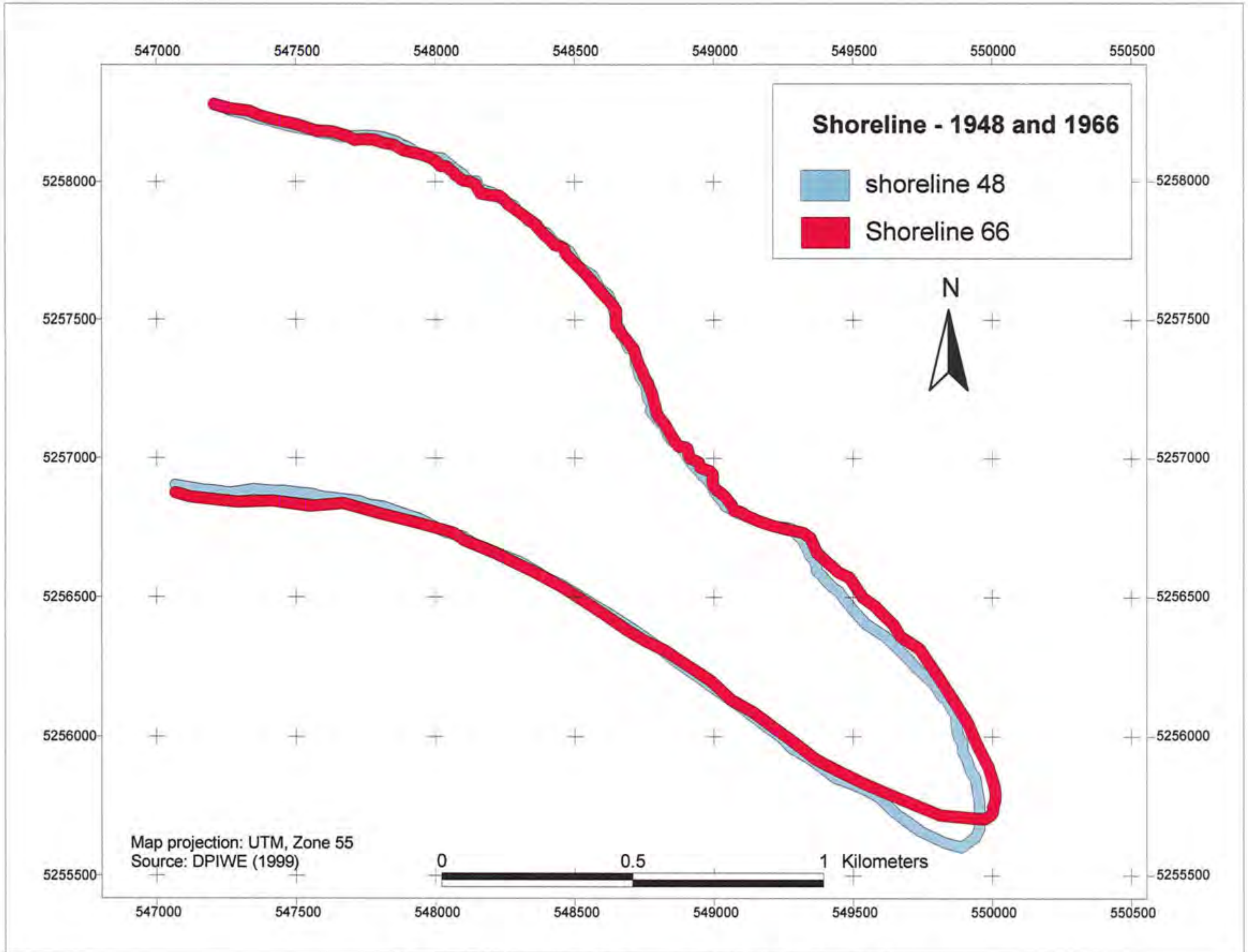


Figure 4.11 - Shoreline of the eastern end of the spit, 1948-1966

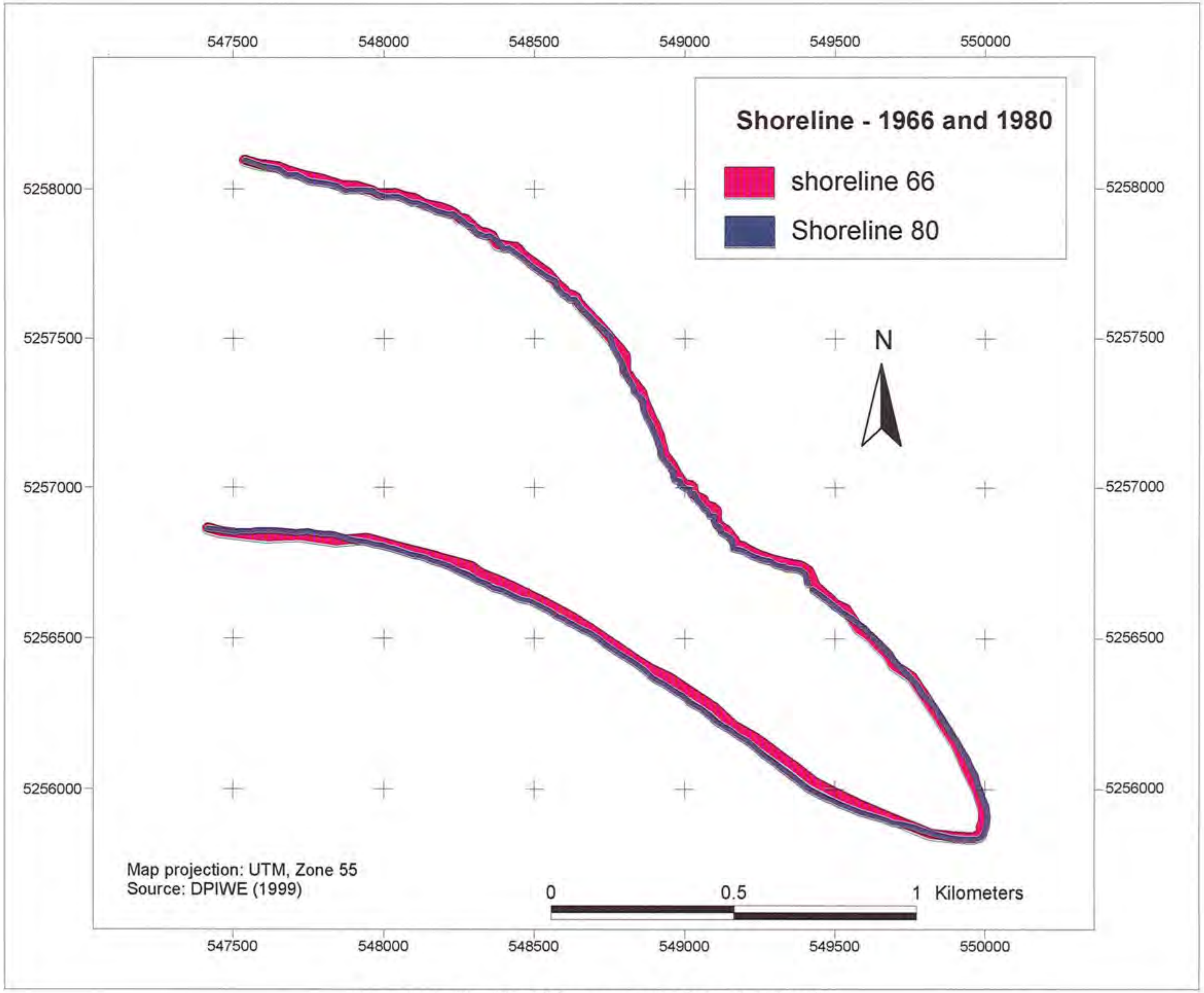


Figure 4.12 - Shoreline of the eastern end of the spit, 1966-1980.

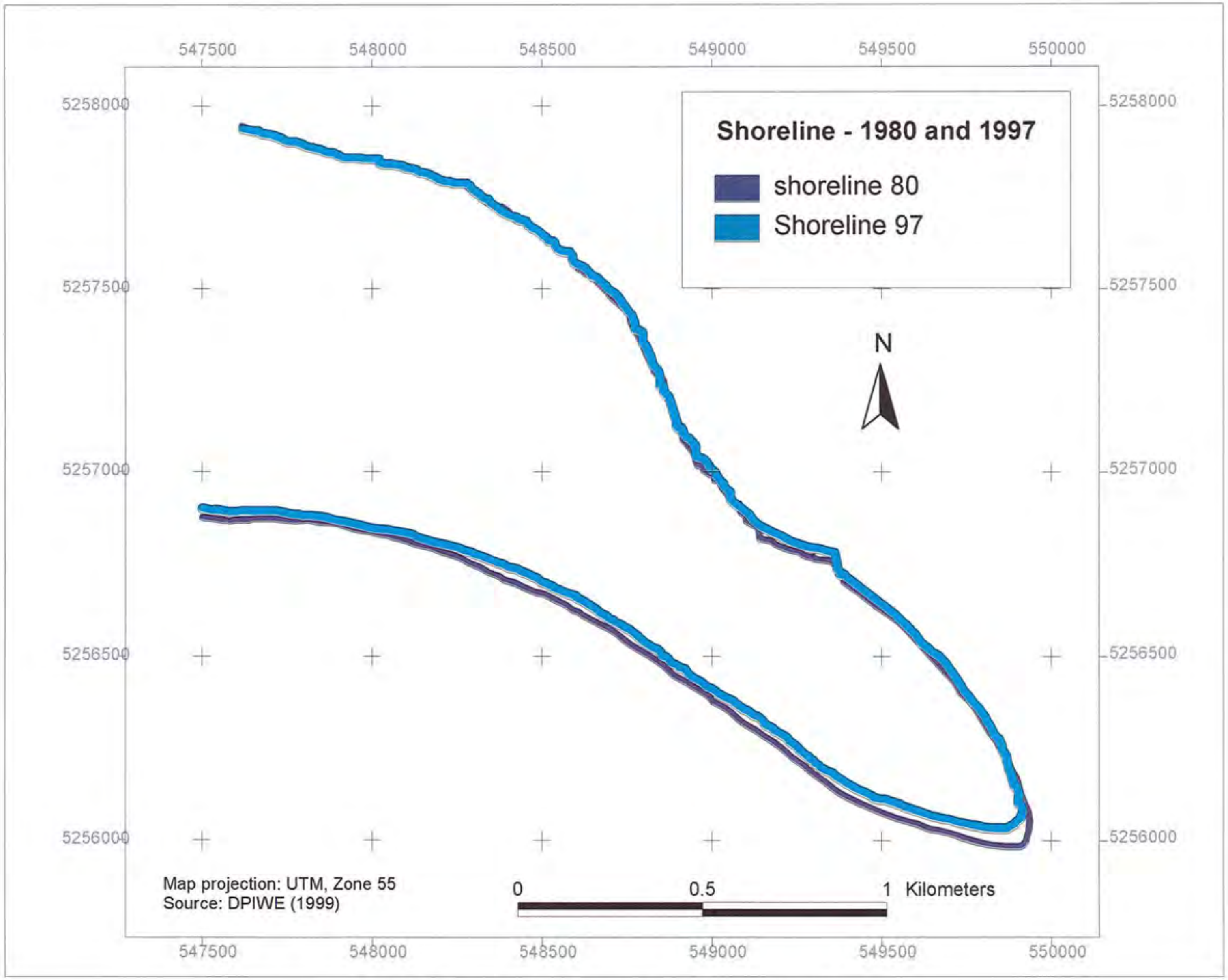


Figure 4.13 - Shoreline of the eastern end of the spit, 1980-1997.

4.6 DISCUSSION

Land cover on the eastern end of the Seven Mile Beach Spit has changed dramatically during the past 50 years These changes reflect the invasion of the introduced species, *Pinus radiata* and *Ammophila arenaria* across the area. The shoreline has migrated up to 60 m in some places since 1948, with the south-eastern end of the spit gradually migrating east and also episodically retreating.

Changes in land cover may be attributed almost entirely to the invasion and rapid colonisation of marram grass and pine tree wildings. Combined, both species have achieved dominance (greater than 50 % cover), resulting in a significant loss of bare sand and the displacement of the native vegetation cover on the spit area studied. Other pressures on the native vegetation, combined with the introduced competitors, could be factors such as drought stress, die back in Eucalypts as a result of low moisture availability in the unconsolidated sand, or disease. The remnant *Eucalyptus viminalis* forest, may have also been subjected to harvesting pressures and land clearance in preparation of plantation areas.

The spread and domination of marram grass and pine trees over the dune area at Sandy Point, could indeed play a significant role in the shaping and rate of migration of the point. The possible effects of marram grass in altering shoreline characteristics are addressed in section 4.6.1.2 below.

4.6.1 Shoreline changes

The changes in the shoreline around Sandy point, correlate with a study conducted by Dobson and Williams (1977), on the changes to Sandy Point between 1894-1969. This study was conducted using historic navigation charts and aerial photography to assess rates of migration. They reported that there was evidence of the spit migrating progressively east into the Pitt Water channel at a rate of 1-2 m per year. These results, together with the results obtained from this study, demonstrate that some coastal landform features in the area are still forming, and accreting. It may be said that with respect to the dynamics of Sandy Point a number of long term trends in change may be possible: Sandy Point may continue to accrete and migrate until a dynamic equilibrium is reached through an increased current flow in the channel.

Alternatively, the point may continue to extend further into the channel, thereby increasing the potential for erosion to occur at Okines Beach on the eastern side of the channel.

There are many possible explanations for the cause of the changes that have been identified in the shoreline over the past 50 years. One cannot be entirely sure as to the exact causes of such changes either, as it is quite likely to be as a result of the combination and interaction of several factors, including human induced factors and natural processes and changes operating.

4.6.1.1 Possible influences of currents on the shoreline

The shoreline is a dynamic system, which is continually changing with different seasons and weather patterns. Storm events play a significant role in shaping beaches and foredunes, through contributing and removing sediment from the foreshore and dune environment.

The end of the spit projects into Pitt Water, which has the influence of fresh and salt-water currents, and Frederick Henry Bay, which is influenced strongly by the Southern Ocean swell, and as a result of this, different sets of currents act on, and influence the shoreline. Changes in current circulation and flow in Pitt Water (and its tributaries), therefore, are likely to be part of the story to explain changes occurring to the shoreline. Pitt Water is influenced by a number of river systems, receiving drainage from the Coal River (its major contributor) and its tributaries, and from other minor streams fringing the estuary (Gallagher, 1997). Changes that occur in the Coal River catchment therefore would influence the flow characteristics and amount of discharge into Pitt Water.

Changes in the circulation of currents and sediment within Pitt Water, may also be partly related to the construction of the Sorell Causeway (initally built in the 1800s), which extends for 1.5 km, restricting the tidal flow to a 500 m bridged section (Gallagher, 1997). Prior to the construction of the bridged section, tidal flow was completely cut off, which had dramatic effects on the estuarine ecosystem. The restriction of flow could cause increased siltation in the estuary, and infilling of the outlet which connects Pitt Water to Frederick Henry Bay.

The water volume flowing in and out of the upper section of Pitt Water, has been calculated to be 11 million tonnes, with an average flushing time of around two days (DPIF, 1996). If there is continued infilling occurring in the channel, the tidal volume entering Pitt Water will decrease due to siltation. The issue of infilling of the channel poses some important management issues, with regards to the shifting of the channel further east, as a result of further extension of Sandy Point. If the channel is forced further east, then erosion at beaches on the other side of the channel (Lewisham and Dodges Ferry) will be exacerbated (Dobson and Williams, 1977; Culver, 1979).

4.6.1.2 Possible effects of marram grass on the shoreline

Human activities place further impacts on natural processes operating in land systems. The Seven Mile Beach Spit is located in an area which is becoming increasingly popular as a suburb close to Hobart. As a result of this, many human induced changes have occurred in the area. One of the more significant impacts on the area, has been the introduction of several highly invasive species including marram grass and pine trees which were both planted in the early 1900s, for stabilisation and harvesting purposes, respectively.

A possible relationship exists, between marram grass invasion along the foredunes of Seven Mile Beach and the decrease in foreshore area over time. As marram grass is such an aggressive coloniser of the foredune environment and a very effective sand trap, the sediment cycling processes become altered (Cullen, 1998; Pemberton and Cullen, 1997; Wiedemann, 1998, 1999). In a natural situation, without marram grass dominating, a balance exists between the incoming and outgoing sand at the dune and foredune interface. With the presence of marram grass, sand becomes focussed in one direction. Onshore movement of sand from the foreshore to the foredune would still occur, but the movement of sand from the foredune back to the shore becomes limited, as a result of the trapping of sand by marram grass.

This alteration of sediment cycling is significant, particularly in the event of a storm acting on the coast. Storm activity consequently, would act upon the foreshore more so than the foredune (that is covered by marram grass), resulting in a net loss of sand from the foreshore, and an overall retreat of the shoreline over time, which is evident along the shore of Seven Mile Beach.

4.7 CHAPTER SUMMARY

The use of aerial photography, in combination with GIS computer programs Arc/Info and Arc/View, have enabled detailed analyses to be conducted of the land cover and shoreline changes that have occurred to the Seven Mile Beach Spit over the period between 1948 and 1997. The technique employed proved to be effective for achieving the objectives of the chapter, which were to map the land cover and shoreline changes to Seven Mile Beach Spit for the years 1948, 1966, 1980 and 1997.

Significant changes in both the shoreline and land cover over the past 50 years have occurred. Since marram grass was first planted on the foredunes of Seven Mile Beach in the early 1900s, it has spread along the entire length of Seven Mile Beach, and also up to 1 km inland. Marram grass now covers over 50% of the eastern end of the spit. Similarly, pine trees (originally planted in extensive plantations on the northern side of the spit) have spread rapidly and colonised areas of bare sand on the spit. Pine tree wildlings and marram grass have progressively invaded and displaced areas of native vegetation and colonised large areas of previously bare sand.

Significant shoreline changes have also occurred on the eastern end of the spit, with a general trend of shoreline migration towards the east, and episodic retreat evident. Maximum displacement of the shoreline was 58 m occurring between 1948-1966, with a further 43 m retreat occurring between 1980-1997.

Several limitations and problems are identified with the results, in that they are merely ‘snap shots’ in time, due to only four time periods being compared. If time allowed, a comparison of aerial photographs taken during different seasons (for example winter and summer) would have been useful to account for seasonal variations in shoreline morphology. Such a comparison would provide a more comprehensive analysis of total shoreline change, as the winter beach profile could then be taken into account as a possible added margin of error.

The results of this chapter are further explored and complimented in the following chapter, where the influence of marram grass on the present geomorphic processes operating on the dune system at Sandy Point is examined. Chapter 5 provides a description of the field experiments conducted at Sandy Point over a four month period, and the results of the interaction between marram grass, sediment transport, dune migration and changing morphology in the short term.

CHAPTER 5

PRESENT MORPHOLOGY AND SEDIMENT TRANSPORT DYNAMICS OF SANDY POINT

5.1 AIMS AND INTRODUCTION

In this chapter the present morphological features of Sandy Point, and the interactions between marram grass (*Ammophila arenaria*), sediment transport processes and dune form, are examined. Specifically, the chapter focuses on the differences between sand transport over bare and vegetated areas, the differences in the amount of sediment transported at 0.5 m and at 0.05 m above the ground, changes to net surface elevation (erosion/deposition) occurring in deflation surfaces, and the rate of dune migration at Sandy Point. It provides a description of the techniques and equipment used for data collection, the field and laboratory methods that were implemented in the study and a discussion of the findings, results and conclusions drawn for each method employed.

The chapter is divided into five sections that describe the field experiments undertaken at Sandy Point. These experiments were conducted over a four month period from July to October of 1999. Section 5.2 provides details of wind data recorded at the Hobart Airport during the study period. Section 5.3 describes the design, experimental procedures, results and discussion of the measurements conducted to assess sediment transport in bare and vegetated regions of Sandy Point. Similarly, section 5.4 details the procedures and results for the use of erosion pins to monitor changes in surface elevation at Sandy Point. An assessment of the rate of change in morphology, dune migration and wind speed and direction over Sandy Point is provided in section 5.5, while section 5.6 presents a discussion of sediment transport dynamics and resultant morphology on the Seven Mile Beach Spit at Sandy Point. A chapter summary is provided in section 5.7.

The information obtained from the period of field sampling at Sandy Point can be analysed in relation to the following aims:

1) To determine the amount of sediment being transported over the study area in relation to wind speed, direction and height of transport.
2) To examine the influence of marram grass on dune form and aeolian sediment transport processes.
3) To obtain an indication of the types of landforms present that contribute to the morphology and geodiversity of Sandy Point, and to examine the rate of migration and change of such features.

5.2 WIND RECORDS

Wind data was obtained from the Hobart Airport meteorological recording station (as described in section 2.3), which is situated approximately 10 km north-west of the study area at Sandy Point. The elevation of the station is 4 m ASL. It is probable that this site does not represent the true wind conditions that occur at Sandy Point, as Sandy Point is likely to be more influenced by winds generated across the surrounding water bodies (Pitt Water and Frederick Henry Bay).

Wind data was obtained for the duration of the field study period which enabled comparisons to be made between sediment transport and wind conditions. The daily maximum, average and maximum gust of wind for each study period was compared, and presented in Figure 5.1. The maximum wind speed reached during the study period was up to 30 knots, with gusts of up to 45 knots occurring during August. For each sampling period, gusts of up to 25 knots and greater were recorded. However these gusts are highly variable in terms of duration (i.e., a strong gust may have occurred of 45 knots, but lasted only for 30 seconds, or a gust might extend for several minutes, thereby having far greater effect on sediment transport). Daily mean wind speed for the study period was 10-15 knots. Statistical tests were conducted to determine possible correlations between sediment transport and wind speed at Sandy Point, however no significant correlations between the data sets were found. This point will be addressed further in section 5.6 in the discussion.

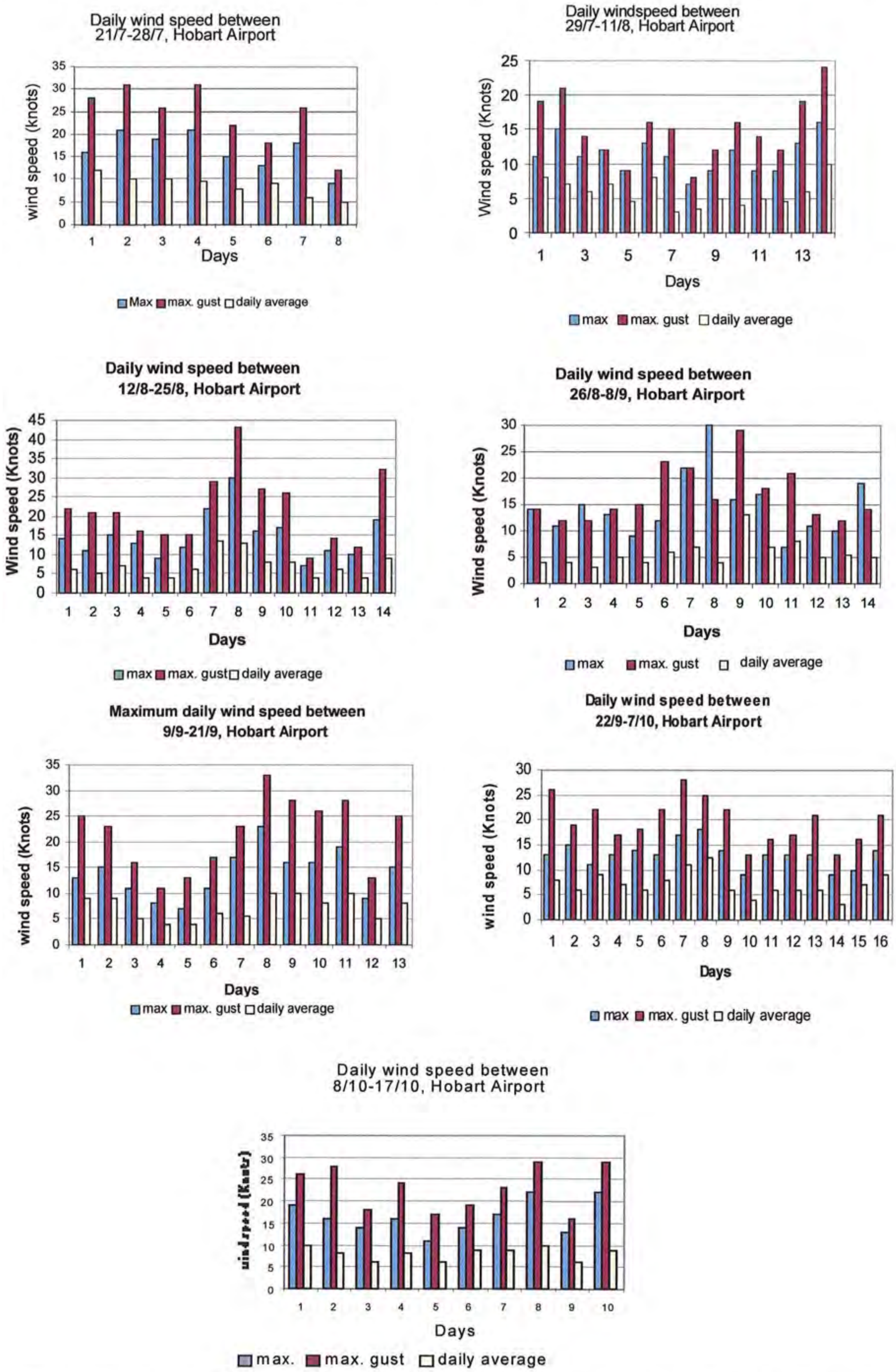


Figure 5.1 - Daily average, maximum gust and maximum wind speed recorded at the Hobart Airport for each field study period.

5.3 SEDIMENT COLLECTORS

5.3.1 Aims and objectives

Sediment collectors were installed at a number of sites on Sandy Point, to assess the amounts of sand moving over time and to look at the effectiveness of marram grass at trapping sand. The effect of different height on sediment transport and grain size was also investigated, testing Heathcote's theory (1983) that the majority of wind blown sand is transported in the lowest 0.5 m of the atmosphere.

5.3.2 Methods

The design of the sediment collectors is based on models used for previous studies of a similar nature (for example, Greeley *et al.*, 1996). Owing to a limited budget, a cost effective (inexpensive) and simple device was used to conduct the field experiments.

The sediment collectors were constructed from 55 mm diameter PVC (poly-vinyl-chloride) piping, cut into lengths of 250 mm. A circle with a diameter of 45 mm was cut 3.5 cm from one end of each length of pipe. This was so that sediment could fall down the length of the pipe and not become re-circulated or blown out once captured. PVC pipe cap ends combined with sealing tape (for added strength and durability) were used to seal off each end of the pipe. The sediment collectors were then attached to wooden garden stakes with strong adhesive tape. The resulting design of the sediment collector can be seen in Figure 5.2.

The pipe lengths were fitted with caps before commencing field work, and then assembled with the stakes *in situ* in the field. The hole size of 45 mm was chosen to fit the diameter of the pipe (which was chosen due to the availability of this size of pipe and for no other important reason), and to maximise the space for sediment to be trapped.

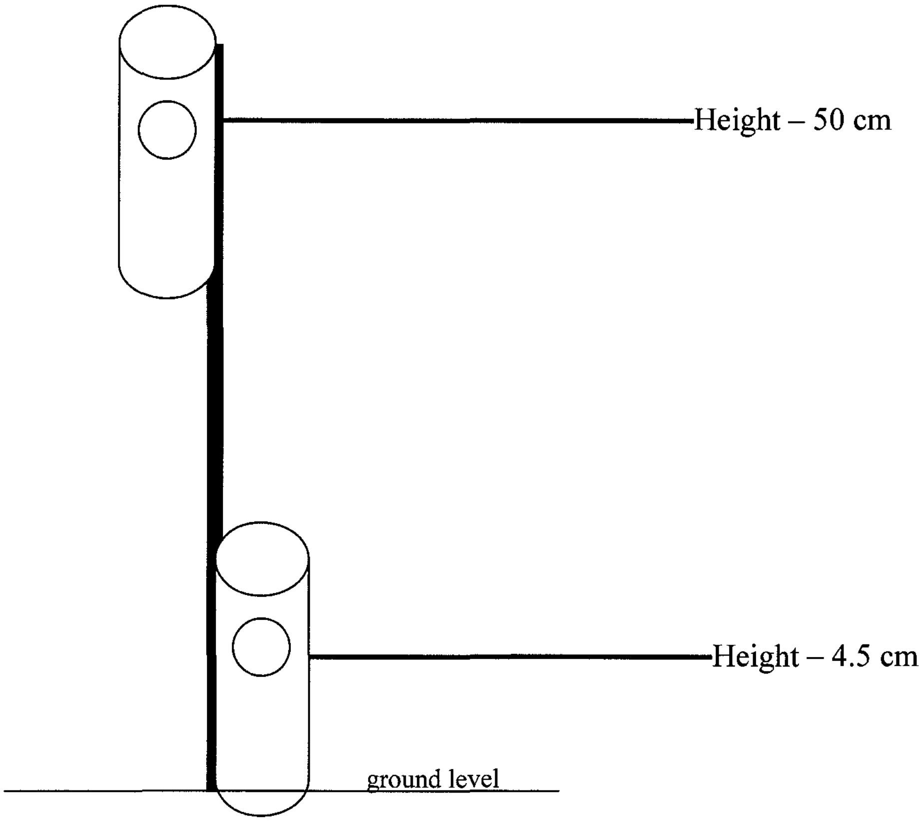


Figure 5.2 - Model of sediment collectors. Sediment collectors attached to a 1.25 m wooden stake. Each hole (opening) is 4.5 cm in diameter.

A total of 19 stakes were driven 0.5 m into sand at various locations at the study area. Two sediment collectors were attached to each stake at different heights above the ground. These heights were chosen as previous investigators demonstrated that most (90%) wind-transported sand is carried at heights of less than 0.5 m in the atmosphere (Heathcote, 1983; Sherman and Hotta, 1990). Subsequently, one sediment collector was placed so that the opening was as close as possible to the ground surface, and the other one was placed at 0.5 m above the surface (as seen in Figure 5.2).

Sites were chosen according to the pattern of either bare sand, or vegetated with marram grass. In addition, several collectors were placed behind an individual or clump of marram grass, to determine if the grass influenced sand deposition or accumulation. The opening of each sediment collector (attached to the stake) was orientated in a north-westerly direction, which is the direction of the prevailing wind over the study site, and also the direction from which the bare mobile sand from the active dune ridge is blowing.

5.3.3 Results

Results of the sediment collector experiments can be examined in relation to the following aims:

1) to examine Heathcote's (1983) theory that rates of sand transport are significantly different above and below 0.5 m; and

2) to assess rates of sand transport in both bare and vegetated areas within the Sandy Point study area.

5.3.3.1 <u>Comparison of upper and lower sediment collectors</u>

Results from the upper and lower sediment collectors, show that there is a distinct change in sediment transport with increased elevation above the ground surface. This was demonstrated through the use of an ANOVA statistical test. The data was log transformed, as a result of the notable difference in variances and large range in standard deviation within and between the data sets. This was caused by the large range of weights in both data sets. Both marram grass sites and bare dune sites showed significant (i.e., probability of less than 0.05) differences in the amount of sediment collected at heights of 4.5 cm compared to the upper collectors positioned at 50 cm.

In comparing all samples collected from upper collectors with all samples collected from lower collectors, a significant difference in sample weight was demonstrated. This point is further illustrated by the large difference in means of each data set. Table 5.1 provides a summary of the ANOVA statistics for all samples collected from upper and lower sediment collectors during the study period.

Grain size analysis of samples collected from the upper collectors demonstrates that the mean sand size transported at elevations of 0.5 m is predominantly fine to very fine, well sorted sand. Particle size diameter ranges from 0.4-0.05 mm, or 1-4.5 ϕ on the Phi scale for sediments deposited in the upper collectors (McDonald *et al.*, 1984).

Table 5.1: ANOVA statistics for the analysis of variance in the data between upper and lower sediment collectors.

	Sample size	Mean	Standard deviation
Upper	62	6.027	25.45
Lower	75	100.1	181.9
Log transformed data			
Degrees of freedom	F-test	Probability	
1	21.99	<0.001	

The grain size of sediment deposited in the lower sediment collectors was generally of the same particle size range as the upper sediments. The most common grain size of the lower collectors (73% of samples) is equivalent to well sorted fine sand, with 5% of the samples containing medium sand. Approximately 10% of the upper sediment was equivalent to very fine sand and coarse silt. Over the entire study period, sediment was found in the lower collectors 89% of the time, whereas sediment occurred in the upper collectors only 41% of the time. Figure 5.3 illustrates the distribution of particle size ranges for upper and lower sediment collectors.

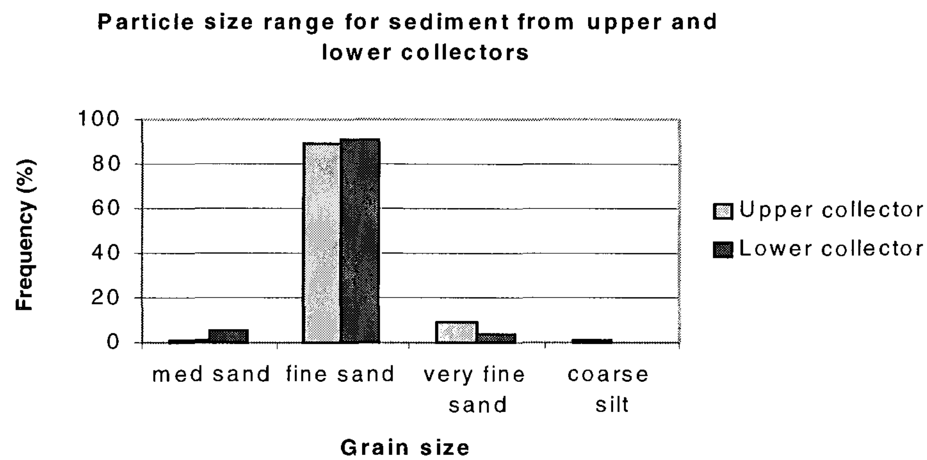


Figure 5.3 – Particle size range and frequency of occurrence for upper and lower sediment collected.

The range of particle sizes transported during the study period support the idea that the majority of sand transport occurs by the saltation process, as discused in section 3.3.

5.3.3.2 <u>Comparison of marram grass and bare sand sediment collectors</u>

A comparison was also made between sediment collectors placed on marram grass dunes and those placed on bare sand dunes. Statistical analysis using ANOVA, revealed that there were also significant differences between the amount of sediment deposited in bare dune sites compared to in marram grass sites. Mean sediment weight for marram grass sites was calculated to be 45.73 g, whereas the mean sediment weight for bare dune sites was 77.98 g. These differences could also reflect the uneven sample size of each data set (i.e., 87 marram grass samples compared to 50 bare samples).

Data was again log transformed owing to notable differences in variances within and between each data set. The transformed data gave a probability of < 0.05 (which is considered to be statistically significant). Bartlett's test of equal variance showed that the variance was acceptable between the data sets (P value = 0.6683). The ANOVA statistics for analysis of variance between marram grass and bare dune sites is presented in Table 5.2.

Table 5.2 - ANOVA statistics for variance within marram grass and bare sand data sets

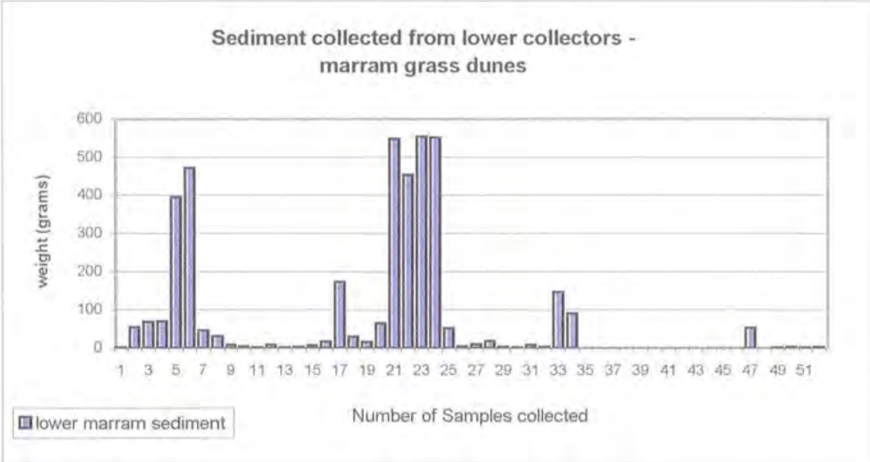
	Sample size	Mean	Standard deviation
Marram grass	87	45.73	127.6
Bare dune	50	77.98	66.3
Log transformed data			
Degrees of Freedom	F-test	Probability	Bartlett's variance
1	4.82	0.0299	0.6683

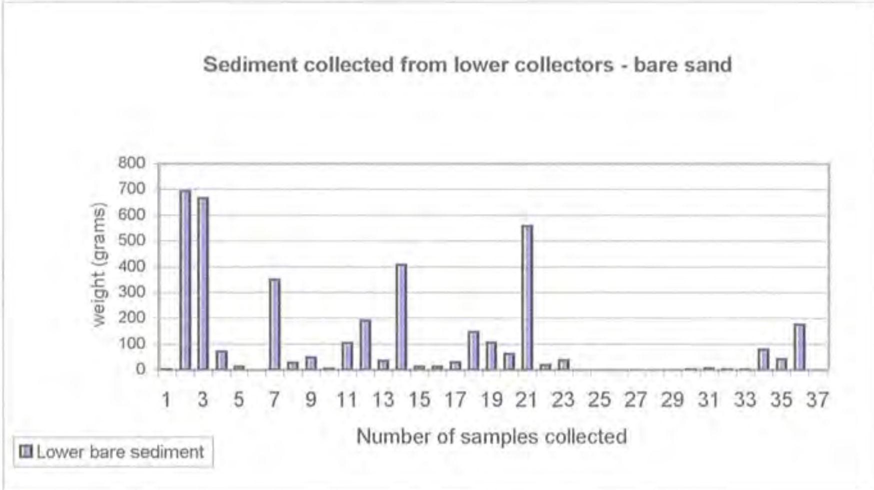
Sediment weights for marram grass and bare dune sites were also compared. The most common sample weight was between 0-50 g for both marram grass and bare sand samples. Marram grass samples had a slightly higher (83%) frequency in this weight class than bare sand samples (74%). The largest sample weight collected from a marram grass site was 550 g (2.3%), whereas the largest samples collected from bare sites were between 650-700 g.

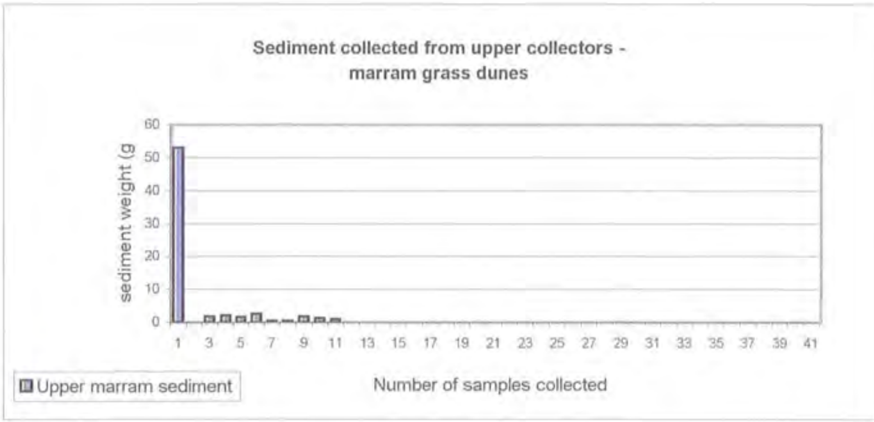
Frequency distribution graphs were plotted for sample weight classes over the study period, to determine the most frequent amount of sediment deposited in both upper and lower collectors, and in marram grass and bare dune sites. Frequency distributions of all the samples, show that the distribution of sediment weights is extremely skewed for each variable, with the most frequent category for all sediment weights being 0-50 grams. This was far more pronounced in the upper collectors than in the lower collectors, where 95 % of samples from the upper collectors had weights of less than 20 g. Sediment collected from the lower collectors was less clustered in one weight category. Of all the lower samples, 66% weighed less than 50 g, 3 % of the samples had weights greater than 600 g, whilst 13% of the samples had weights between 300-550 g. The distribution of upper and lower, marram grass and bare sand, sediment weights are presented in Figure 5.4. All weights collected should be considered as a minimum owing to the possibility that wind may have blown some of the sediment out of the collectors or the collectors were completely filled during a collection period.

It was expected that the collectors placed in the marram grass dunes (particularly behind a clump of grass) would collect more sediment. However, as it turned out most of the collectors placed in marram grass were effectively sheltered from the force of the wind, with the exception of those placed closer to the supply of mobile sand. Despite this, evidence to support the effectiveness of marram grass at trapping sand was visible on several occasions. Plate 5.1 provides a view of sand being trapped as it is blown through an isolated clump of marram grass, forming a typical shadow dune in the direction of the prevailing wind.

Plate 5.1 - Shadow dune forming behind an isolated clump of marram grass. Note: lower sediment collector is almost buried.







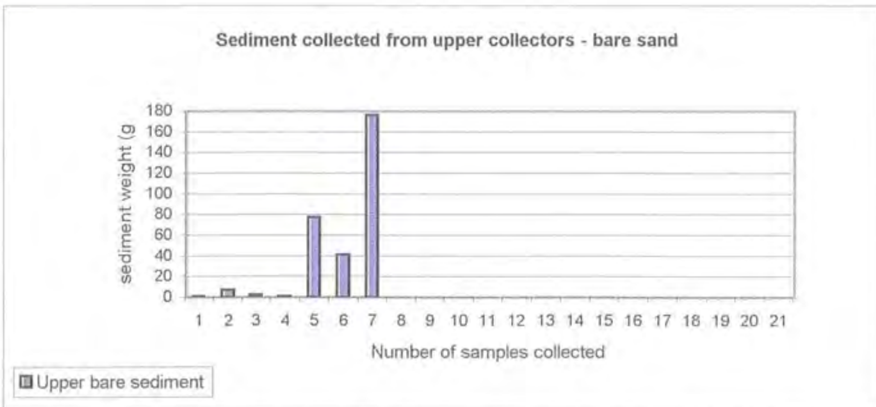


Figure 5.4 – Distribution of weights collected from upper and lower and marram grass and bare dune sites at Sandy Point.

It must be noted that the amount of sediment collected between marram and bare sites, and upper and lower collectors, is directly proportional to the proximity of the collector to the mobile sand supply. Thus sediment collectors positioned closest to the advancing dune face, were more frequently filled than those positioned further away. This relationship is demonstrated in Figure 5.5.

Sediment collectors were placed at distances of up to 800 m away from the active dune system. Sediment collectors (both marram and bare sites) placed on the northern side of the large deflation basin (with distances of up to 50 m away from the bare mobile sand) were frequently inundated with sand. Several collectors were buried completely on more than one occasion, as demonstrated in Plates 5.2 and 5.3.

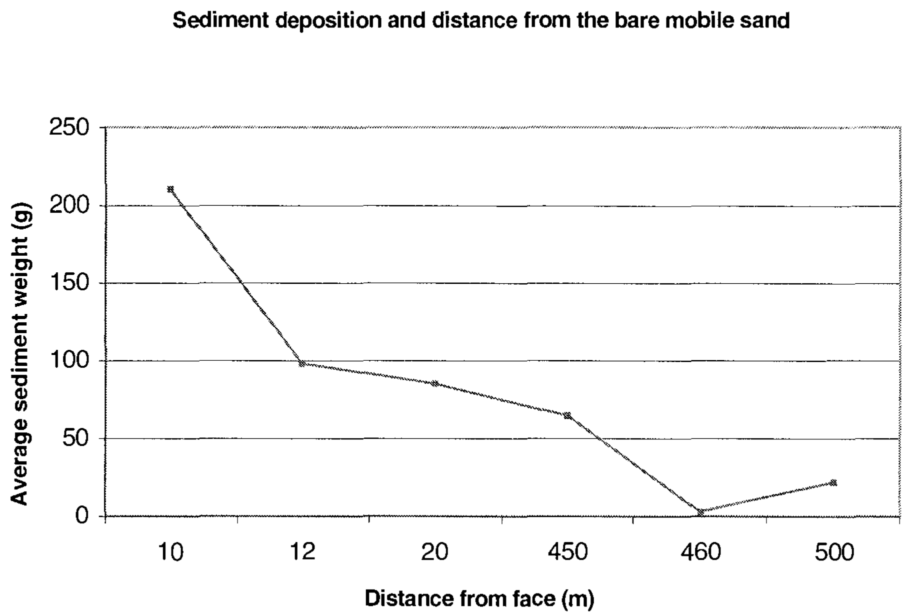


Figure 5.5 – Relationship between amount of sediment deposited and distance from bare mobile dunes.

Plate 5.2 - Sediment collector infront of a clump of marram grass, facing the direction of the migrating dunes – 11/8/99. Height of opening = 4.5 cm above the surface.

Plate 5.3 - Sediment collector 2 weeks later – 25/11/99. Sediment collector had been completely buried by sand from the advancing dune face. Sand is being deposited immediately behind the grass (as seen in Plate 5.1).

5.3.4 Discussion

The sediment collector experiments conducted at Sandy Point show significant relationships between the amount of sediment deposited and the height at which sand is transported above the ground. Differences between sediment deposited at marram grass sites and bare dune sites were compared and found to be significant also.

The effects of marram grass on altering sediment transport and deposition was demonstrated to some degree through the field experiments conducted at Sandy Point. Ash and Wasson (1983 in Viles, 1988), found that a cover density of 30 percent or less is insufficient to inhibit aeolian sand transport. The marram grass cover at Sandy Point is much higher than 30% in some areas (with up to 100% cover), while other areas have little or no vegetation cover. Topographic variations must also be considered when looking at the effectiveness of vegetation on modifying/inhibiting sand movement. Clearly the proximity of the sediment collectors to the mobile dune was also an important consideration when examining the relationship between sediment deposition and vegetation cover.

Analysis of the data obtained from upper and lower sediment collectors demonstrates that there are significant differences between the amount of sand collected between the two heights. These findings clearly support Heathcote's theory that the majority of wind blown sand is transported in the lowest 0.5 m of the atmosphere.

Despite the strong statistical evidence that demonstrates the differences between the amount of sediment collected in upper and lower and vegetated and bare collection sites, it is difficult to single out the influence of any particular landscape feature, such as marram grass, on sand transport. There are many possible contributing factors that may have influenced the results of the sediment collection study including the variation in wind direction and proximity to sand dunes. In addition, variability in the size of the data sets that were compared (i.e. more sediment collectors were placed in marram grass dunes than at bare dune sites), limited length of study duration, small sample size, and lack of replicate sites with similar parameters, may have had a direct bearing on the results. Further comparisons of the relationship between wind data (recorded at the site) and sediment transport would be useful to complement the findings of sediment transport occurring at Sandy point and to determine if a different wind regime exists on Sandy Point, compared to that recorded at the Hobart Airport meteorological station.

5.4 EROSION PINS

5.4.1 Aims and Introduction

Erosion pins are a very simple and effective method of measuring and monitoring the amount of erosion or deposition (surface lowering or raising) occurring in a particular area over a period of time (Jungerius and Van der Meulen, 1988). Erosion pins have been used successfully by Jungerius and Van der Meulen in 1988, to monitor the development of dune blowouts in the Netherlands. Whilst it is recognised that there are some disadvantages associated with the erosion pin technique, the erosion pin is regarded as one of the simplest, and certainly cheapest, methods of monitoring the amount of surface raising or lowering occurring across an area.

Some of the problems or inaccuracies associated with using erosion pins, have been reported by Haigh (1977), in Brown (1997). These include the possible disturbance to the site associated with the installation and recording of the erosion pin, inconsistency and/or inaccuracy in measurement of the pin at different time intervals, and also the erosion pin properties such as width and height that could contribute to altering surface structure.

The main purpose of the erosion pin experiments was to gain an indication of the change in surface elevation (lowering or raising) occurring through several minor (but active) blowout and trough areas at Sandy Point. Sites were chosen with the aim to determine whether further scouring was contributing to the extension of the large deflation basin located on the edge of the three transects.

5.4.2 Methods

Erosion pins used at Sandy Point consisted of 1.25 m wooden garden stakes, with a width of 2.5 cm. A total of 27 erosion pins were used in the study. The length of 1.25 m was seen as adequate for the purposes of the study, and due to the limited time frame for sampling it was assumed that there would not be this much deposition or erosion occurring over three months.

Erosion pins were arranged in three transects at three separate sites over the study area. Transect 1 was installed in an area that appeared to be scouring out, at the edge of a large deflation basin. The erosion pins were placed across a small deflation surface at 2 m intervals between two higher dunes at either side of the blowout, visible in Plate 5.4. Each stake was initially set in the sand to a height of approximately 0.6 m with heights measured 7 times along each transect during the four month study period

Measurements of the height of the exposed pin were taken every two weeks (recorded to the nearest mm). The measurements were conducted using the same side of the pin throughout the study, and performed by one person using the same measuring device. The height of each pin was measured from the top of the pin to the sand surface.

Transects 2 and 3 were placed in areas that appeared to be active, in either deposition or erosion, and were also located on the edge of the large deflation basin. Plate 5.5 shows the position of Transects 1 and 2 through a trough amongst marram grass hillocks, whilst Plate 5.6 provides a view of the three transects in relation to the study area and the prevailing wind direction.

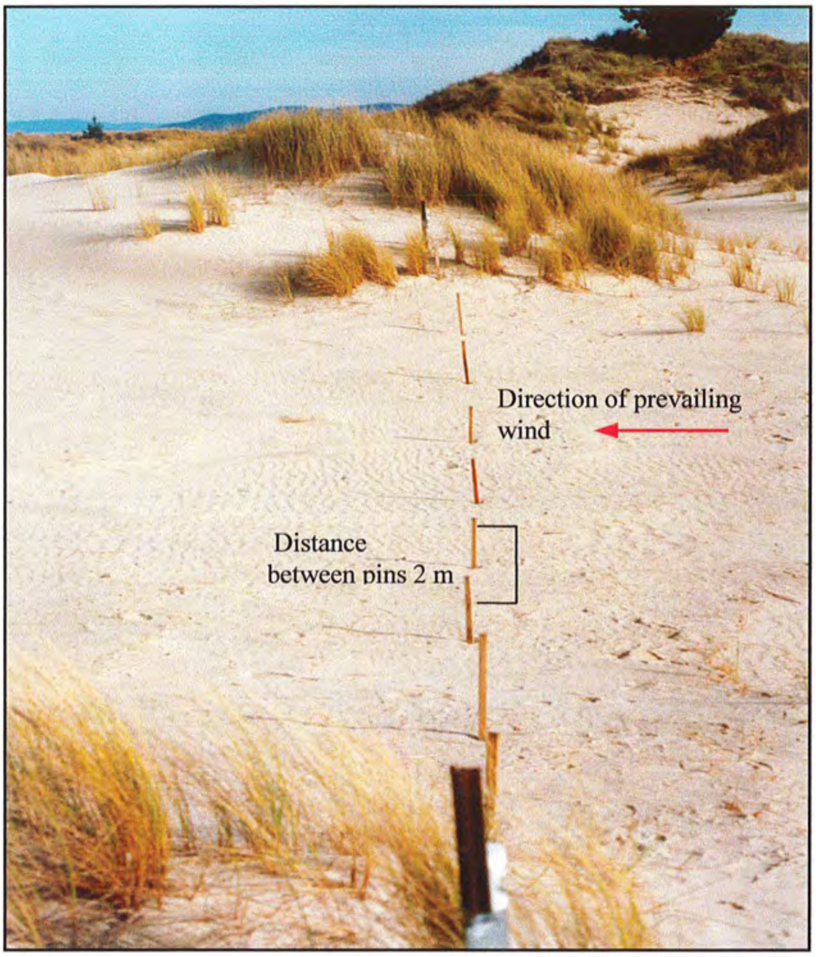


Plate 5.4 - Arrangement of erosion pins through a small deflation surface, transect 1. Small ripples can be seen, indicating the direction of the prevailing wind.

Plate 5.5 - Location of erosion pins Transect 1 & 2, Sandy Point

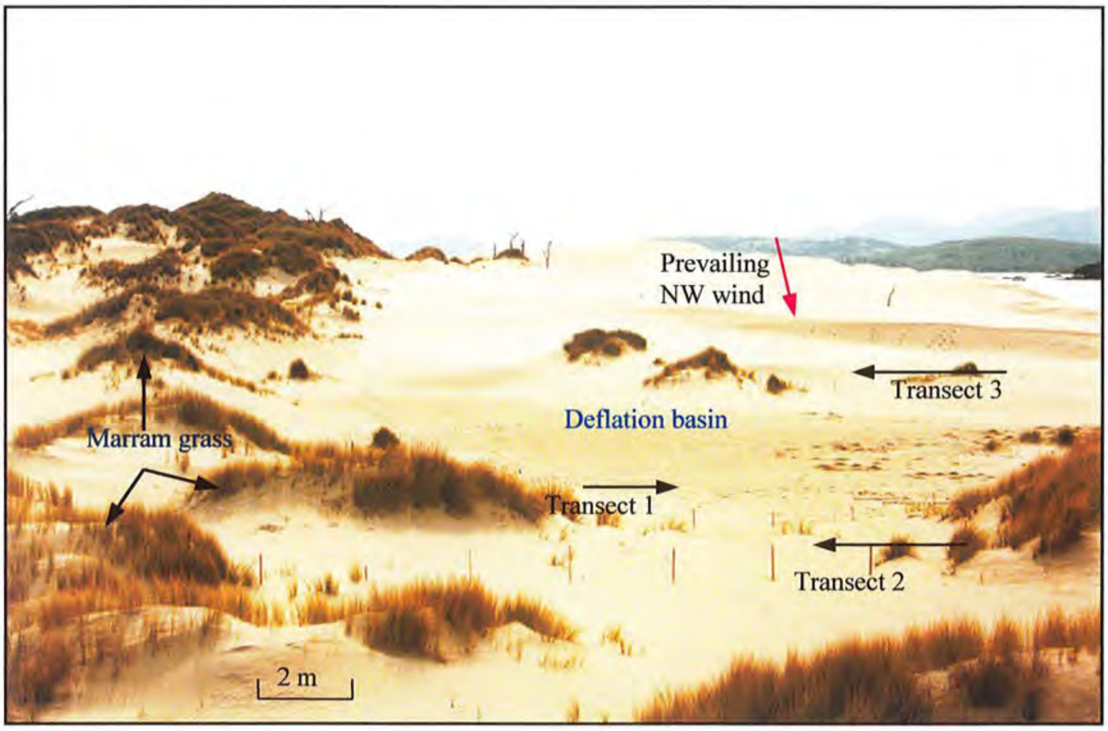


Plate 5.6 - Location of erosion pin transects in relation to the study area at Sandy Point.

5.4.3 Results

Results from the erosion pins, indicate that there was much temporal and spatial variation in the height of the surface through the erosion pin transects during the study period. Transects 1 and 2 were generally found to be sites of erosion, however both sites appeared to show no particular trend or pattern in either continuous erosion or deposition occurring between measurement intervals. For some of the time, the sites appeared to be eroding, and other times deposition was occurring. Individual pins also showed differences in erosion or deposition within the same transect. Transect 3, however, showed dramatic evidence of deposition and surface raising occurring through the middle of the transect over the three month study period.

Initially, Transect 3 appeared to be subject to some degree of scouring, with episodic periods of deposition. The effects of the advancing dune face on surface elevation through Transect 3 became evident during the last 4 weeks of the study period. Surface raising through transect 3, occurred in some places by up to 2 m above the original measured surface.

The results from Transects 1 and 2 indicate that surface lowering (scouring) is occurring frequently through the middle of the trough, with some deposition occurring on the vegetated dunes on either side of the transect (refer to Plate 5.6 for an over view of the transect). In Transect 1, only 1 out of 10 pins experienced deposition, and 4 pins out of 10 experienced deposition in transect 2. The sites of deposition correlate with sites of marram grass tussocks. One pin in particular on both transects (positioned in the lee of a clump of marram grass), appeared to be receiving deposition throughout the sampling period, whilst the other pins in the same transect (where there was no marram grass) measured surface lowering. Of the 9 pins through Transect 3, 5 pins experienced deposition. Graphs detailing the changes in surface elevation, occurring at each site over the study period are presented in Figures 5.6a and 5.6b.

The large amount of deposition occurring at Transect 3 is associated with the close proximity of the site to the mobile dune ridge at Sandy Point. Transect 3 was initially installed ~10 m south of the active dune system. However, towards the end of the study period several pins had been completely buried. Indeed 3 of the pins were buried under 1 m of sand in the middle of the transect. Plates 5.7 and 5.8 illustrate the advancing dune face through site 3, over a 4 week period.

Average change in surface elevation for each transect was calculated. This was taken as being the average amount of change (erosion or deposition) for all the pins in each transect. Results indicate that all transects are experiencing erosion or sand loss to some degree during the study period. Transect 2 appears to be subject to the largest amount of scouring, with an average change in surface elevation of –2.63 cm occurring over the study period.

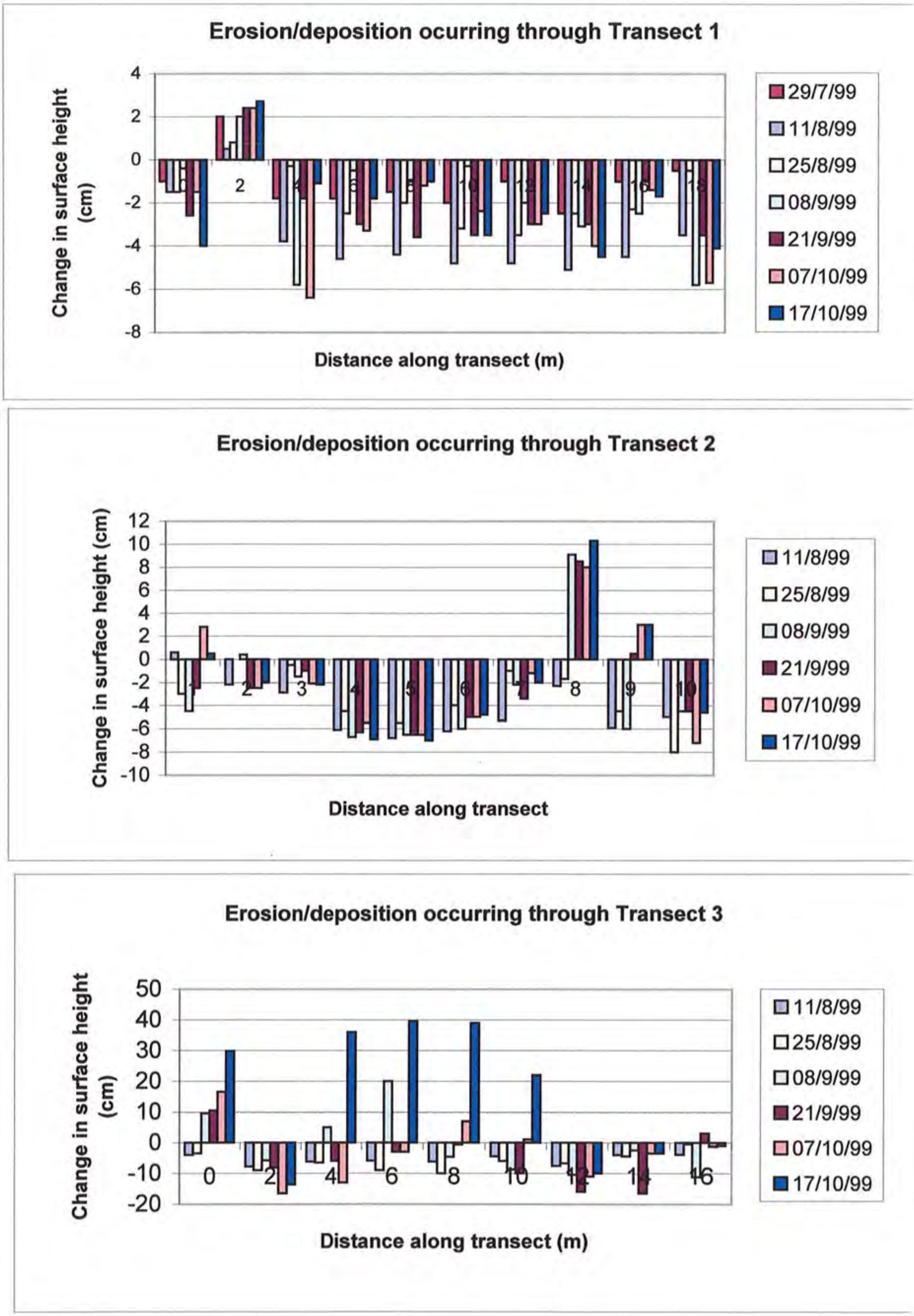
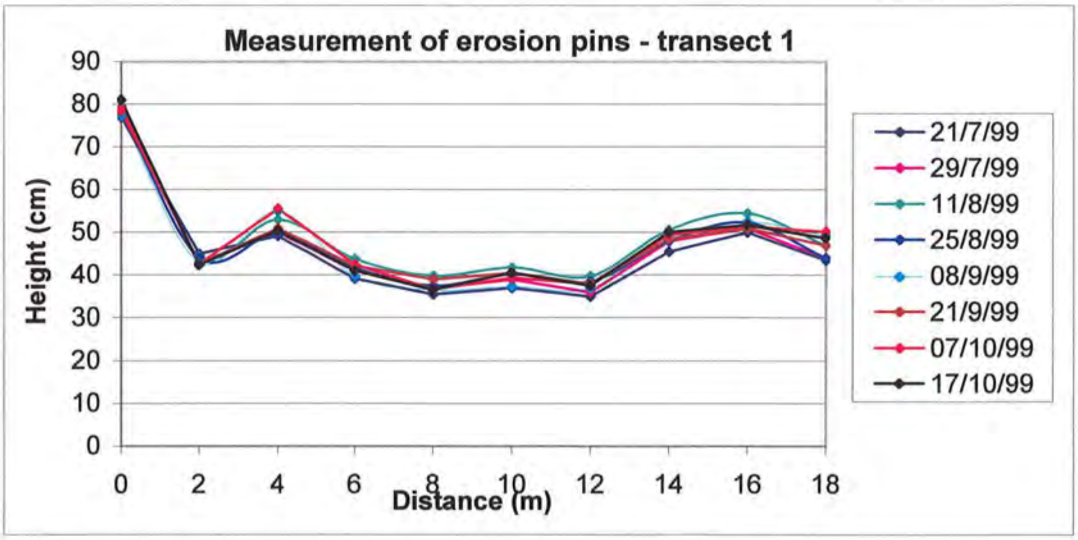
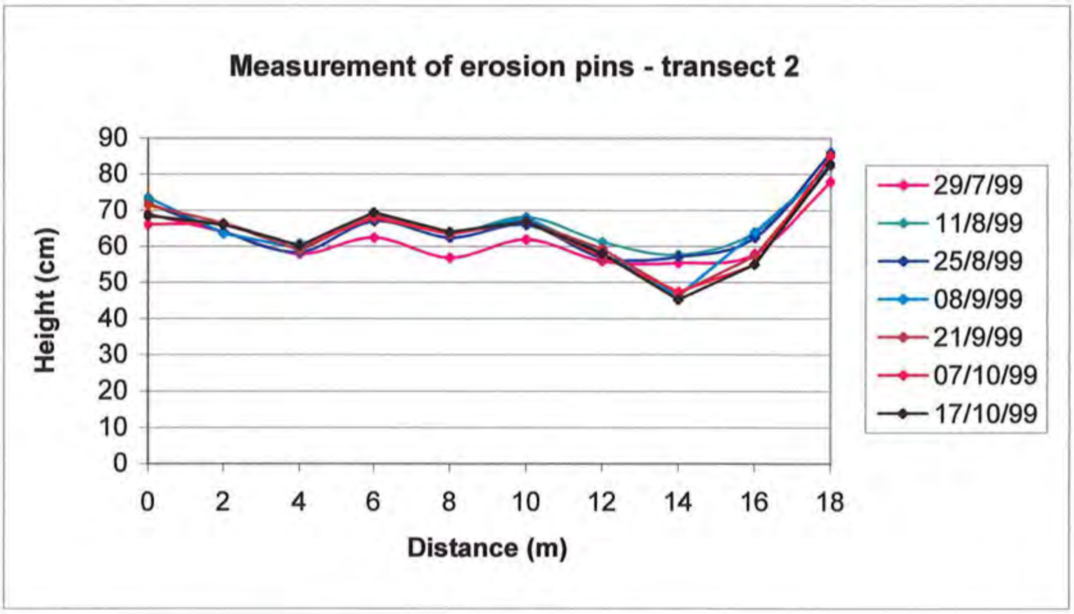


Figure 5.6a - Changes in surface elevation at Sandy Point through three small deflation areas.





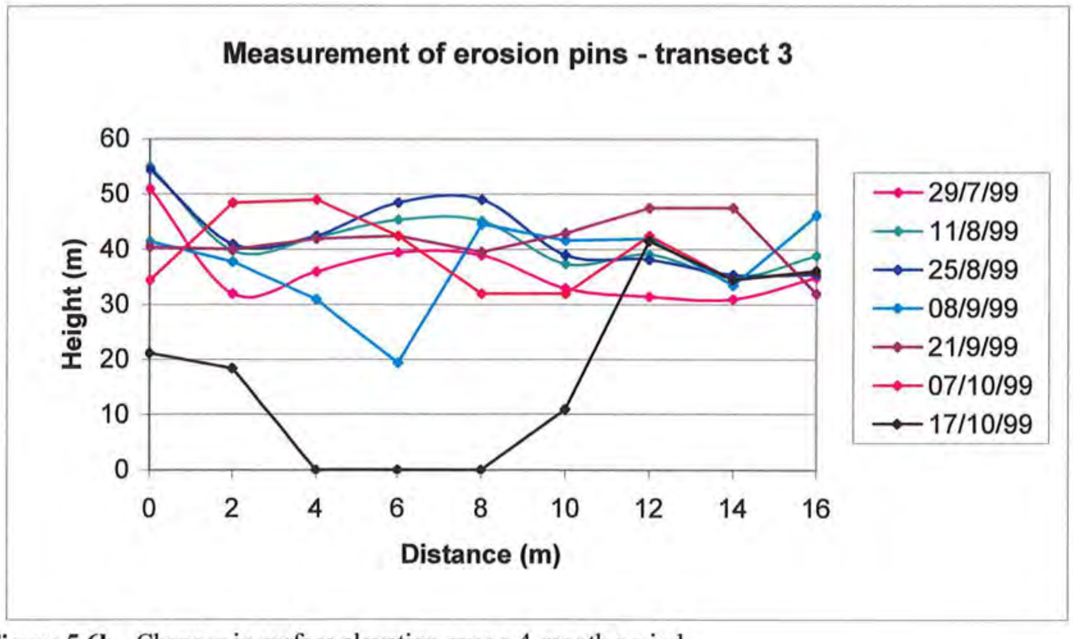


Figure 5.6b - Changes in surface elevation over a 4-month period.

Plate 5.7 - Erosion pin Transect 3 – 8/9/99. Dune face positioned approximately 3 metres away from transect.

Plate 5.8 - Erosion pins Transect 3 – 7/10/99 (4 weeks later). Dune face has advanced over 3 m to the transect of erosion pins.

When looking at the maximum and minimum changes in surface elevation for each transect, transect 3 shows the highest amount of surface change occurring, with a change of > 39.5 cm. This figure is however, not an accurate indication of the true value for surface raising that occurred, as some of the pins had been completely buried. The figure (of 39.5 cm), therefore represents the height of the erosion pin, and not the total change in surface elevation, which would exceed this value by 1 m or more. The minimum amount of sand loss over the study period was –0.3 cm recorded, in Transect 1. The figures calculated for change in surface elevation for each transect are presented in Table 5.3.

Table 5.3 - Change in surface elevation for the three erosion pin sites at Sandy Point, between July-August, 1999.

	Transect 1	Transect 2	Transect 3
Average change in surface elevation (cm)	-2.22	-2.63	-0.86
Minimum change in surface elevation (cm)	-0.3	0.4	-0.5
Maximum change in surface elevation (cm)	-6.4	10.3	39.5

5.4.4 Discussion

Once again, owing to the limited duration of the study period, the results of the erosion pin experiments cannot be used to provide an accurate indication of the overall trend of the processes occurring at Sandy Point. Therefore the results must be considered in the context of the length of the study period, to infer what might be expected in the long term. Rates of deflation across blowout surfaces, have been measured by Jungerius and van der Meulen (1989) who found that over a period of four years most of the blowouts grew in length against the prevailing wind and the average amount of surface lowering was approximately 3.3 cm. This figure compares to the results obtained from the present study (ranging between –0.86 to –2.63).

Several factors may have contributed to the results obtained from the erosion pin study. Disturbance to the site is possibly the most significant source of generated error, that may have arisen during the study period. Disturbance to the site could have been as a result of human disturbance to the surface in the form of recreational activities such as horse riding, trail bike riding, dogs and walking across the surface.

Such forms of disturbance is highly likely to have occurred, due to the high level of use of the study area – especially on the weekends by people picnicing at Sandy Point.

Disturbance to the site could have been enhanced by the frequency of measurements of the erosion pins (increasing the amount of surface trampling, compaction, and possible displacement of sand). However, disturbance of this nature may be somewhat balanced by the dynamic and highly changeable nature of the coastal environment. This is highlighted by field observations made on several occasions, where disturbances such as footprints and marks drawn in the sand, disappeared completely sometimes in less than 10 seconds (depending on the strength of the wind at the time).

Disadvantages of the erosion pin technique have been discussed by Haigh (1977, in Brown 1997, p. 240), who mentions that disturbances to the site occur by the 'presence, installation and recording of the erosion pins'. For this reason Brown (1997), states that erosion pins are perhaps more suitable to studies that continue for several years or more rather than for studies of shorter time periods, due to problems associated with the extrapolation of such results. However, in a highly unstable and changeable environment, such as at Sandy Point, erosion pins have proved to be an effective method of monitoring short term changes occurring to surface elevation, as has been demonstrated by this study.

5.5 MEASUREMENT OF A DUNE SLIP FACE

5.5.1 Aims and Introduction

An extensive and active dune slip face is present at the study site. This feature formed the basis for another set of experiments conducted over the field study period at Sandy Point. The slip face is highly mobile as a result of an absence of vegetation cover, and is evidently advancing south towards a large deflation surface. Plate 5.9 illustrates the proximity of the mobile sand ridge to the deflation surface. The purpose of the measurements was to determine the rate of migration and changing form of the slip face in terms of slope, height and position. According to Mowling

(1998, p 55), there are three factors that affect the rate of dune migration (advance): 1) distance from the shore - with increasing distance from the shore, there is a decrease in the effectiveness of wind in transporting sand (Illenberger and Rust, 1988); 2) proximity of the dune to sand stored on the beach; and 3) height of the slipface.

Pemberton and Cullen suggest also, that dune movement can be monitored through the use of marker points such as star pickets or wooden stakes. The stakes provide a fixed point from which to measure the distance to the active front of the dune, and hence give an indication of the rate of movement of the dune. Such experiments have been conducted on the west coast of Tasmania to monitor natural dune blows, where the dunes have moved distance of 6 m, in as many months (Pemberton and Cullen, 1997b). The concept of this technique was employed for the monitoring of the movement of a slip face at Sandy Point.

5.5.2 Methods

To monitor the movement of the slip face at Sandy Point, a transect was established so that measurements of height, slope, and length of the face could be measured. A bearing was taken from the western (landward) end of the face towards a stationary point (a house) at Dodges Ferry. This was done so that the distance to the face could be measured from the same place each time, to gain an indication of the amount of movement occurring.

A 75 m tape was laid out along the line of the bearing, and anchored at regular intervals to prevent the tape from moving off the line of the bearing. At every 5 metres along the tape, measurements of height, slope and distance to the bottom of the face from a fixed point on the line of the bearing were recorded. The location of the face in relation to the transect was also noted - i.e., whether the face was north or south of the measuring tape. If the face was absent at a particular 5 m interval, it was recorded as zero and the following measurement was taken at the next occurrence of the face along the transect.

This series of measurements was conducted fortnightly, over a period of three months, to determine the rate of migration of the face southwards, and to assess the degree of change occurring in the morphology of the dune slip face.

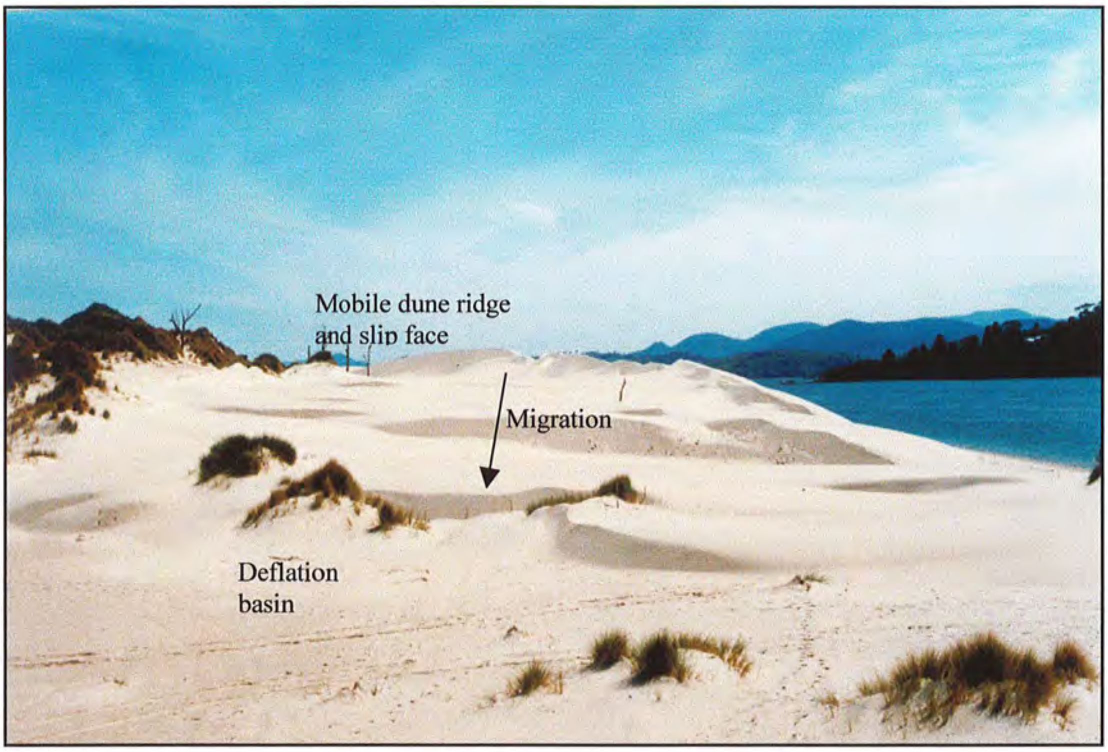


Plate 5.9 - Mobile sand ridge advancing towards a large deflation basin.

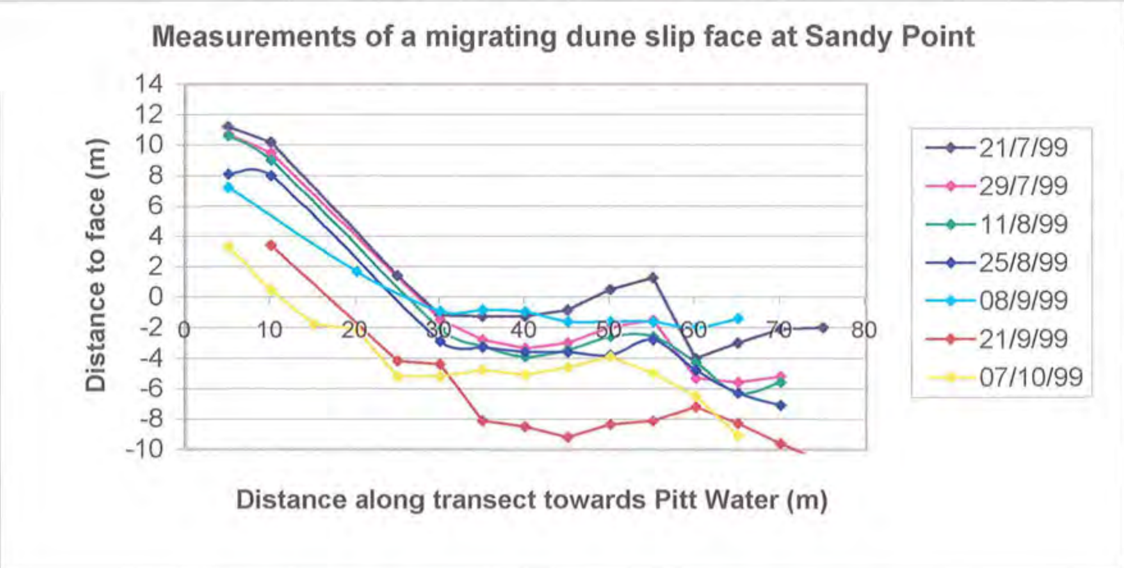
5.5.3 Results

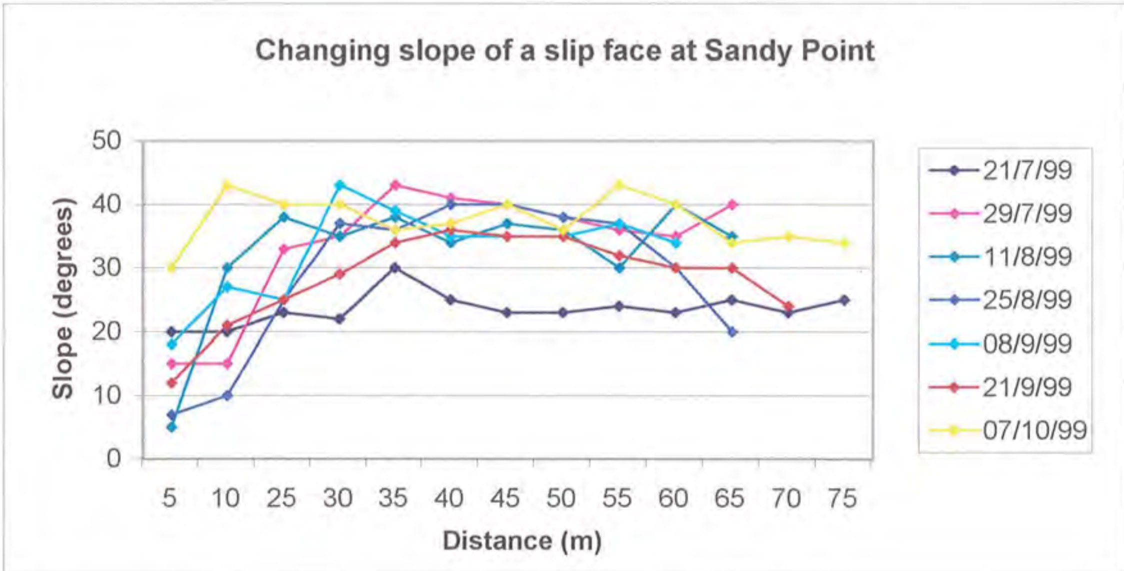
Results from the measurements of the slip face indicate that the face is continually changing in terms of slope, height and distance (measured to the face from a fixed point). It can also be demonstrated that the migration of the face was not always associated with advances forward, as on some occasions the face appeared to have retreated. Graphs of changes in face slope, height and migration are presented in Figure 5.6. and discussed below.

In order to calculate sediment transport rates, various components are required, including grain size and grain sortedness, bulk density and total volume of sediment. Sherman and Hotta (1990) describe three methods of estimating sediment transport including: measurement of volumetric changes in source/sink areas; sediment trapping (as discussed in section 5.2); and tracer experiments.

Bulk density of the sand (weight of sediment sample (kg) /volume of core (m^3)), was calculated using the 'traditional core method', which uses volume and weight of the substrate. This enabled rates of sand transport and dune migration to be calculated. A bulk density of 1163.3 kg/m^3 was calculated. The total volume of sand moving from the slip face was then calculated by multiplying the total volume of the sand in the slip face (height x total distance moved x length of face) with the bulk density. This gave a volume in kg, which was then converted into tonnes. The total volume of the sand moved during the study period, was calculated to be approximately 2502 tonnes.

The changes occurring to the slip face at Sandy Point were evident on a fortnightly time interval. Figure 5.7 presents the measurements (migration, slope and height) of the slip face over the study period. The face appears to be advancing steadily, but episodically southwards. Despite the general trend of advance, two pronounced episodes of retreat are apparent (8/9/88 and 7/10/99). During these two periods, evidence of variable winds could be seen through the development of two distinct faces, within the main dune face, as illustrated in Plate 5.10. Analysis of the wind data recorded at the Hobart Airport (discussed in section 5.2), revealed that wind from three dominant directions (NE, SE and NW), occurred for a week during the two separate study periods in September and October. The period of predominantly south-easterly wind, may have caused the retreat in the dune face that is evident in Figure 5.7.





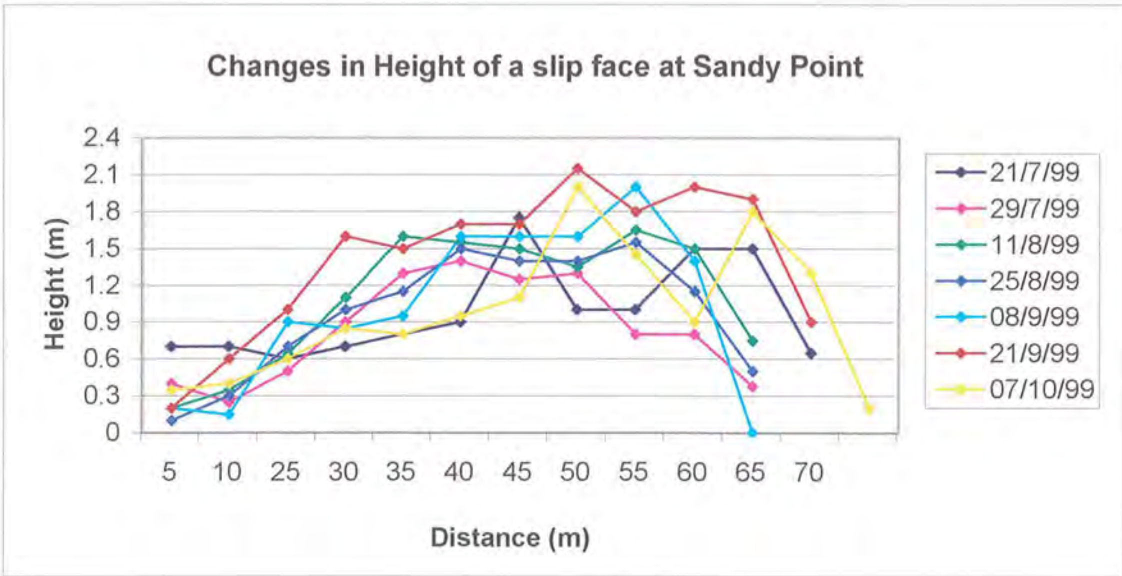
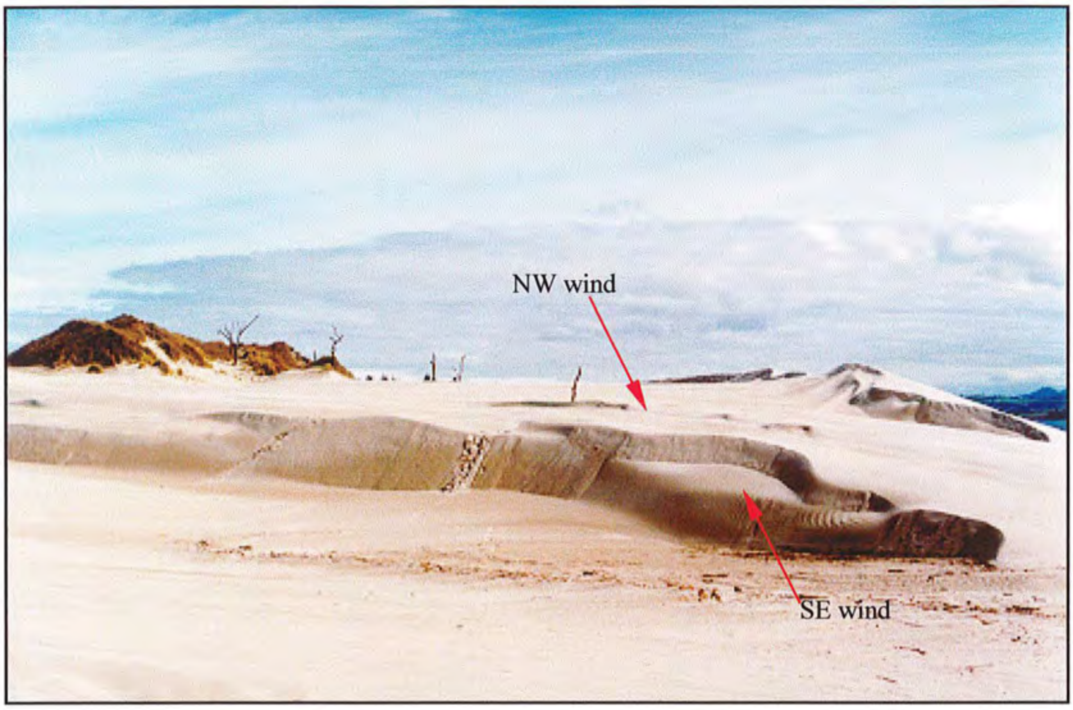
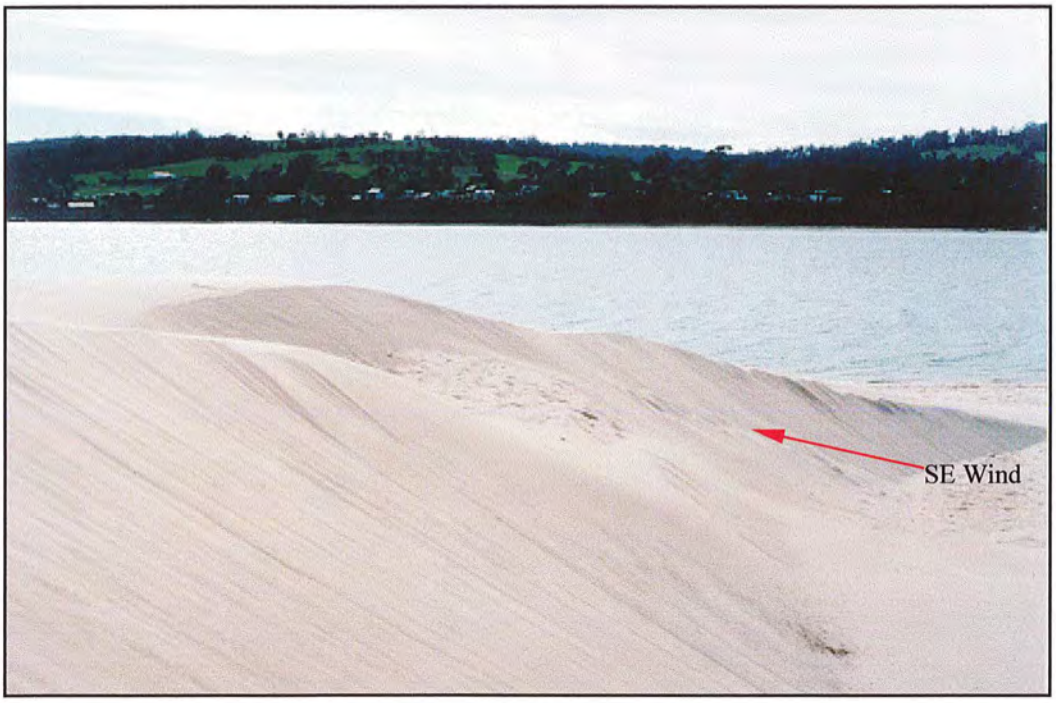


Figure 5.7 - Changes in the morphology of a migrating slip face at Sandy Point. (Jul-Oct).



8/9/99



7/10/99

Plate 5.10 - Evidence of two dominant wind directions occurring during September and October at Sandy Point. The wind blowing from one direction for a period of time shapes the slip face with a sharp ridge line. A change in wind direction therefore acts on the face from a different angle, thereby creating two distinct slip faces

The height of the face varied substantially over the study period. In addition, the height of the face varied along the length of the slip, tapering out towards each end, and becoming increasingly higher towards the centre. The average height of the slip face is 1.1 m, however, heights of 1.5-2 m were commonly recorded. Slope was measured at 5 m intervals along the length of the face. The maximum slope recorded over the study period was 43 degrees, which is exceptionally steep, considering the angle of repose of sand is given as between 30-33 degrees (Bagnold, 1941). This angle however, was calculated for very dry desert sand, which would be dis-similar to wet coastal sand.

The average slope of the slip face over the study period was calculated to be 31 degrees. The slope of the face became progressively steeper in some places over the study period. Generally the slope of the face did not change dramatically along its length, i.e., slopes were fairly constant over one study period, however, between study intervals, the slope of the face changed quite a lot, becoming much steeper towards the end of the study period. This is illustrated in Plate 5.11a and 5.11b.

Plate 5.11a - Slip face showing gentle slope gradients, with height of face tapering at each end.

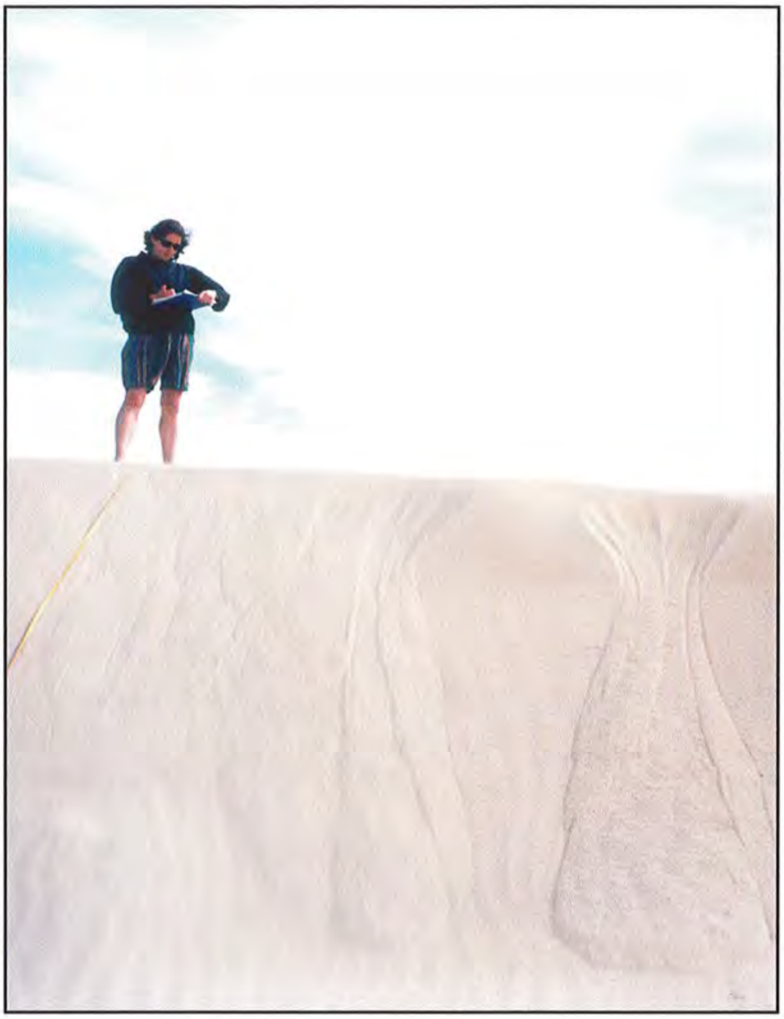


Figure 5.11b - Steep section of the slip face. Slope of the face is 40 degrees, with a height of 1.8 m. Small scale slip zones can also be seen, forming as a result of the over steepened slip face.

5.5.4 Discussion

The measurements of a dune slip face at Sandy Point, demonstrate that the rate of movement or advance of the dune is not constant. Instead, the rate relates to the interplay of factors such as wind strength and direction, sand transport dynamics and grain characteristics, and topographical and vegetation influences. The changes identified and measured are relatively short term changes, but could be used to extrapolate yearly rates of dune migration at Sandy Point. Owing to the highly changing and dynamic nature of dune systems, however, extrapolation of short term results may not provide an accurate indication of the rate of dune migration that may occur over longer time periods. The short term changes could be used to obtain an indication of possible rates of movement that would be expected, given the knowledge of the rate of advance over a four month period.

Several factors may have contributed to the reliability and accuracy of the measurements taken of the slip face over the course of the study period. Similar problems and inaccuracies to those discussed previously, with the other field components in sections 5.3.4 and 5.4.4, have contributed to possible inaccuracies or bias in the results. Whilst the rate of dune migration and dune form is largely related to wind strength and direction, topography and sediment transport dynamics, disturbance to the site may also be a contributing factor.

There is a great deal of human disturbance occurring at the site, particularly on the high dune ridges and steep faces, which have no vegetation cover, thereby providing perfect sites for recreational activities such as horse riding, trail bike riding and sand boarding. Such activities could have a significant influence on the rate of movement of the slip face and also on the dune form. All three forms of recreation create major disturbance to the dune, causing sand slides and collapse of slopes to occur. Such disturbance would strongly influence the amount of sediment transport occurring, and certainly contribute to the acceleration of some processes.

Disturbance to the site (hence creating further potential inaccuracies in the results) also occurred through the measurement process, which required walking over the dune face several times. This effect is probably negligible though, and is unlikely to have any significant influence on the results. Another source of potential error arose from the placement of the transect, from which measurements were taken each time. This problem was further highlighted by wind gusts, blowing the tape off the line of the bearing, and therefore contributing to the generation of small inaccuracies. Despite all the possible sources of disturbance generated from human activity, it may be said also that these effects are negligible, when considering the rate of change to the dune system that was evident between fortnightly intervals.

5.6 CHAPTER SUMMARY

Through conducting the set of field experiments at Sandy Point, the relationship between sediment transport, wind characteristics, topography and vegetation interactions have been examined. Results have demonstrated that there is a significant difference in the amount of sediment transported at different heights above the ground surface, and that the majority of wind blown sand is transported in the lowest 0.5 m of the atmosphere. Significant differences were also found between sediment collected on bare dune sites compared to those on marram grass sites. However, it should be recognised that these results were biased by the proximity of the bare sand collectors to the advancing dune face and bare sand ridges, and therefore do not represent a true indication of the differences between the two.

The invasion of marram grass to the area (demonstrated in Section 4.4) has profound effects on sediment transport processes and dune morphology of a particular area. A common occurrence or trend found throughout the field study was the development of pronounced shadow or lee dunes in the wake of grass clumps, as well as other distinctive forms, related to the interplay of wind and vegetation.

Dune systems are among the most dynamic and naturally unstable landform features in Tasmania, prone to extremely rapid change. The use of erosion pins demonstrated that on average, the three sites experienced net erosion or scouring (up to 10 cm at some pins), however erosion pin transect three also experienced a substantial amount of deposition, resulting in the burial of some of the pins in over 1 m of sand. Dune migration rates and total volume of sand moving over the area were calculated and reveal that over 2500 tonnes of sand was moved during the study period with a maximum rate of ~ 25 m movement recorded over the four month study.

All three techniques used to conduct field measurements at Sandy Point indicate that sand transport within the area is complex, with results demonstrating that sand movement reflects: the direction and strength of wind; the height at which particles can be entrained and moved in suspension; sediment characteristics including size and shape; and the influence of topographical features and the presence of a vegetation cover.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

The primary aims of this thesis were to assess the past and present morphologies of the eastern end of the Seven Mile Beach spit, and to document the interaction between form, process and the influence of vegetation on bedform features. Analysis and interpretation of a sequence of aerial photographs, in conjunction with field work conducted on the end of the spit at Sandy Point, has enabled documentation of such changes and an understanding of the sediment transport dynamics operating there. Within the study, four main aims were considered and each of these will be addressed in turn.

1) Assess the shoreline changes to the eastern end of Seven Mile Beach spit since 1948

This aim was achieved through the use of aerial photography combined with GIS computer programs. The methodology proved to be very effective in recording long term changes occurring in a complex and dynamic system. There have been significant changes and transitions in the shoreline land cover types and bedform features present on the spit, over a relatively short time period of 50 years. Analysis of the shoreline between 1948 and 1997 indicates that the 'toe' of the spit appears to be migrating slowly eastwards into the channel, and also episodically retreating in other places. These trends have also been observed by Dobson and Williams (1977) and Culver (1979), both of whom state that Sandy Point is still actively growing and accreting.

A relationship between shoreline retreat and marram grass invasion has been inferred along Seven Mile Beach. Shoreline retreat on the southern facing side of the spit, appears to coincide with the substantial increase in marram grass over the area between 1948 and the present time. This reflects a change in sediment transport equilibrium between the foreshore and primary dune interface.

2) document changes in land cover on the Seven Mile Beach spit since 1948

In conjunction with mapping the shoreline changes, an analysis of the changes in land cover on the spit over the same time period was investigated using a similar approach. Significant changes in land cover on the spit are apparent between 1948 and 1997. The impact of marram grass and pine trees on the land cover and morphology of bedform features is most pronounced. Since 1948, the land cover of the spit has undergone some dramatic and over-riding changes that are directly associated with the spread and invasion of the two vigorously colonising exotic species. Combined, these species now have increased in cover from 15% in 1948 to almost 90% of the entire spit area. This has resulted in a substantial decrease in the species diversity within the Seven Mile Beach Protected area. The area of bare mobile dune sand has progressively become inundated with marram grass and pine trees over the past 50 years. Similarly, the area of native grassland and open *Eucalyptus viminalis* forest has also been diminished substantially over the same 50 year period as a result of exotic species invasion.

3) Determine the influence of marram grass on sediment transport processes and dune morphology

Marram grass has impacted upon numerous coastal dune systems around the world and become the dominant species (Wiedemann 1996, 1998; Pemberton and Cullen, 1997; Cullen, 1998b; Hertling, 1997). With regards to the present situation at Seven Mile beach, particularly at Sandy Point where a large and active mobile dune system exists, the impact of marram grass on the morphology of the dunes is indeed evident. Dunes have become over-steepened (with slopes of up to 47 degrees recorded on marram grass dunes) and display a characteristic hummock-like form, as a result of the growth of vertical and horizontal tillers. The effectiveness of marram grass at trapping sand was also investigated, and results demonstrate that the grass has a pronounced influence on sand transport and deposition.

Bird (1993) states that if a foredune becomes stabilised with vegetation such as marram grass, then there exists an increased tendency for the mobile dune field to do the same. This is of particular importance when considering the extent to which marram grass has invaded over the foredunes of the spit, as the potential for the bare dune field to become stabilised is high.

4) sediment transport dynamics

With regards to the sediment transport dynamics operating at Sandy Point, it can be said that the area is part of a complex and dynamic landscape, with many factors contributing to the formation, movement and stability of these "soft" landforms. Dunes and sandy coasts are arguably the most dynamic landforms in Tasmania, and prone to very rapid change. Measurements conducted on a migrating slip face at Sandy Point demonstrates that even over relatively short time periods there was considerable movement and migration occurring. The total migration (advance and retreat) of the slip face during the study period was calculated to be approximately 25 m, with evidence of variable wind directions influencing the advance or retreat of the face. Slope (ranging between 5-43 degrees) and height (ranging between 0.2-2.2 m) measurements of the slip face further indicate the highly changeable nature of the bare dune system.

Wind data from the Hobart Airport meteorological station provided an indication of the prevailing wind direction and variable speeds and gusts, which correlated to episodic advance or retreat of the slip face. Whilst the Hobart Airport weather recording station is situated only 10 km north-west from the field site at Sandy Point it is possible that Sandy Point may experience a slightly different wind regime, due to its proximity to large water bodies, thereby increasing wind speed and gusts to the area. Further experiments and the installation of annemometres to record wind speed and direction at Sandy Point, over an extended period of time are needed to verify this.

Sediment collection experiments demonstrate that there were significant differences in the amount of sediment transported at different elevations above the ground surface. This supported Heathcote's theory that the majority of wind blown sand is transported in the lowest 0.5 m of the atmosphere. Significant differences between the amount of sediment collected at bare dune and marram grass sites were also recorded. These results demonstrated that there was significantly higher amounts of sand deposited in collectors that were placed in bare sand compared to those in marram grass. Such results were unexpected, as previous studies (Hesp, 1981; Hertling, 1997 Haber, 1998; Wiedemann 1988) have found that the reverse trend is apparent. The results however, can be explained by the close proximity of some of the collectors in bare sand to the mobile dune ridge. A relationship was also found between proximity of the sediment collectors to the source of bare mobile sand, and the amount of sediment that was deposited. This relationship was found to influence the results obtained quite markedly, in that sediment collectors positioned 10 metres from the mobile dune ridge experienced significant amounts of deposition and were frequently inundated with sand. As might be expected, collectors placed at distance of up to 800 m away from the mobile dune area, experienced substantially less deposition.

Measurements of erosion pins over the four month study period, also highlighted the dynamic nature of the area and revealed that sites were experiencing net erosion over the four month study period. One transect in particular, however, experienced a significant amount of deposition, and erosion pins were buried under over 1 m of sand.

In summary

The macro scale geomorphological features present on the Seven Mile Beach spit, including transverse and sub-parallel dune ridges, extensive, mobile sand sheets and recent beach and dune sands and tidal flats, are considered to be outstanding examples of marine and aeolian sedimentary features for Tasmania (Bradbury, 1993; Dixon 1995). As such, conservation and protection of these significant features from threats and degradation must be considered. The threats to sandy coastlines and dune systems in Tasmania are many and varied. Activities which have impacted on dunes and dune forming processes in Tasmania include some forms of commercial and recreational activities, such as sand extraction/mining, off-road vehicles (including trail-bikes), grazing, burning and land clearance. Management strategies and or guidelines therefore, are needed that specify the types of potentially damaging activities that pose threats to areas such as the Seven Mile Beach spit and dune system at Sandy Point, and for the control and or restriction of such activities from occurring.

Marram grass invasion also poses a serious threat to the integrity of the dune system at Sandy Point and many other coastal dune systems around Tasmania. If marram grass continues to dominate and invade at Sandy Point, which is inevitable, it will slowly take over the entire area, locking up thousands of tonnes of sand, and thereby altering natural sediment transport processes and preventing the transfer of sediment from one area to another.

There is probably no feasible management option with regards to the further spread of marram grass over the spit area due to its already extensive distribution, and certainly no feasible option for the removal of the grass. Isolated pine trees are presently being removed from the end of the spit, and pines remaining in the plantation area are to be harvested within the next few years before the cutting rights expire in the year 2010. In place of the pines, native vegetation should be planted where possible to minimise potential erosion and to re-establish some of the species diversity that was once present on the Seven Mile Beach spit.

Whilst it may not be possible to remove existing marram grass at Seven Mile Beach, vigorous attempts at preventing further spread of marram grass into areas where it currently is not present, or areas where it does not have a strong hold, would be extremely worthwhile. This is of particular importance for beaches located in the World Heritage Area of south-western Tasmania and other coastal National Parks where the grass has not yet established.

REFERENCES

Bagnold, R.A. (1941) *The physics of blown sand and desert dunes.* London, Chapman and Hall. 265 p.

Bagnold, R.A. (1954) *The physics of blown sand and desert dunes.* William Morrow and Co., New York. 265 p.

Bell, A. (1988) Alien dune plants reshape our beaches. *Ecos.* **54**: 3-6.

Bird, E.C.F (1968) *Coasts: An introduction to systematic geomorphology.* **4**. Australian National University Press, Canberra. 246 p.

Bird, E.C.F (1984) *Coasts: An introduction to coastal geomorphology.* Third edition. Australian National University Press, Canberra.

Bird, E.C.F. (1993) *The coast of Victoria: The shaping of scenery.* Melbourne University Press, Carlton. Victoria. 324 p.

Boorman, L.A. (1977) Sand dunes. *In*: Barnes, R.S.K. (Ed.) *The Coastline: A contribution to our understanding of its ecology and physiography in relation to land-use and management and the pressures to which it is subject.* John Wiley and Sons, London. 356 p.

Bowden, A.R. and Kirkpatrick, J.B. (1974) The vegetation of the Rheban Spit, Tasmania. *Papers and Proceedings of the Royal Society Tasmania.* **108**: 199-210.

Bowman, G.M. (1986) The Holocene Evolution of the Rheban Spit, Tasmania. In *Papers and Proceedings of the Royal Society of Tasmania.* **120**: 23-32.

Bradbury, J. (1993) *A preliminary geoheritage inventory of the Eastern Tasmania terrane.* Parks and Wildlife Service, Tasmania.

Bressolier, C and Thomas, Y.F. (1978) Studies on wind and plant interactions on French Atlantic coastal dunes. *Journal of Sedimentary Petrology.* **47**: 331-338.

Brown, K.J, (1997) *Evaluation of the controls on hillslope sediment transport in a small arid zone catchment.* PhD. thesis, Department of Geography and Environmental Science, Monash University. 370p.

Bureau of Meteorology (1999a) http://www.bom.gov.au/climate/averages/tables/cw 094008.shtml. Accessed on 2nd August, 1999.

Bureau of Meterology (1999b) *Temperature, Wind and Rainfall readings for Hobart Airport - 1958-1999.* Climate and Consultancy Section, Tasmania and Antarctica Regional Office, Hobart.

Burns, K.R. (1977) *The Geomorphology of the Central Bruny Island Area.* BSc. Honours thesis, Department of Geography, University of Tasmania.

Carolin, R. and Clarke, P. (1991) *Beach plants of south-eastern Australia.* NSW Department of Soil Conservation and Land Management. 115 p.

Chick, N. (1999) Personal communication. BSc.Hons. Department of Geography, University of Tasmania.

Chiu, T.Y. (N.D.) *Sand transport by wind.* Technical Report No. 1. Department of Coastal and Oceanographic Engineering, University of Florida. National Science Foundation, Washington D.C.

Colhoun, E.A (1977) A sequence of late Quaternary Y at Pipeclay Lagoon, south-eastern Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **111**:1-12.

Cooper, W.S. (1958) Coastal sand dunes of Oregon and Washington. *Geological Society of American Memoirs.* **72**:1-142.

Christensen, E.M., and Jones, M.C. (1997) *Before They Built the Bridge: an Anecdotal History.* Graphic Plus, Tasmania.

Cromer, W.C. (1996) *Geodiversity values of the Seven Mile Beach Protected Area.* Unpublished Report to Hepper Marriott Pty. Ltd. And Jerry de Gryse Pty. Ltd

Cromer, W.C. and Sloane, D.J. (1976) *The Hydrology of Seven Mile Beach.* Unpublished Report: 10. Mineral Resources Tasmania, Department of Infrastructure, Energy and Resources. 25 p.

Cullen, P. (1998a) *Coastal dune systems of south-western Tasmania: their morphology, genesis, and conservation.* Parks and Wildlife Service Tasmania. Nature Conservation Report No. 98/1.

Cullen, P. (1998b) <u>Ammophila arenaria</u> *and* <u>Euphorbia paralias</u>*: Serious threats to the integrity of the South West Tasmanian coastline.* Unpublished report, Parks and Wildlife Service, Tasmania.

Culver, R. (1979) *A review of some current coastal problems and comments on coastal zone management in Tasmania.* A report to the Minister for Lands, State of Tasmania. Civil Engineering Department, University of Adelaide.

Davies, J.L (1959) Sea level change and shoreline development in southeastern Tasmania. *Papers and Proceedings of the Royal Society of Tasmania.* **93**:89-95.

Davies, J.L. (1958) Wave refraction and the evolution of shoreline curves. Reprinted from *Geographical Studies*, Vol. V, No. 2, 1958. Birkbeck College, London.

Davies, J.L. (1960) Beach alignment in Southern Australia. *Australian Geography.* **8**: 42-44.

Davies, J.L (1963) *The geomorphological influence of the Southern Ocean Swell.* Department of Geography, University of Tasmania. 1-7.

Davies, J.L. (1972) *Geographical variation in coastal development.* Oliver and Boyd, Edinburgh. 204 p.

Davies, J.B. (1988) *Land systems of Tasmania region 6: South, East and Midlands – A resource classification survey.* Department of Agriculture, Tasmania.

De Gryse, J. (1996) *Seven Mile Beach Protected Area Draft Management Plan, for public comment.* Department of Environment and Land Management. Hepper Marriott Tasmania Pty Ltd And Jerry de Gryse Pty Ltd. 170 p.

Department of Mines (1995) Tasmanian Geological Survey – Geology of south-east Tasmania. 1:250,000, AMG, Zone 55. Tasmania Development and Resources, Hobart.

Dieckhoff, M.S. (1992) Propagating dune grasses by cultivation for dune conservation purposes. *In*: Carter, R.W.G., Curtis, T.G.F. and Sheehy-Skeffington, M.J. (Eds.) *Coastal Dunes.* Balkema, Rotterdam.

Dixon, G. (1995) *Aspects of Geoconservation in Tasmania: A preliminary review of significant earth features.* Occasional Paper No. 32, Parks and Wildlife Service, Tasmania.

Dobson, J.E. and Williams, G.J. (1977) *Towards an Environmental management plan for the eroding coastal zone at Dodges Ferry, south-eastern Tasmania.* Master of Environmental studies, Department of Geography and Environmental Studies, University of Tasmania. 171 p.

DPIF, (1996) *Coal River Catchment – Natural Resource Assessment.* In: Gallagher, S. (ED.) (1997) Part of a study undertaken for the development of a Catchment Management Strategy for the valley. 65 p.

Duncan, F. and Duncan, D. (1996) *Vegetation resources: Seven Mile Beach Protected Area.* Unpublished report to Hepper Marriott Pty. Ltd. and Jerry de Gryse Pty. Ltd.

Evans, O.F. (1942) The origins of spits, bars and related structures. *Journal of Geology.* **50**: 846-865.

ESRI (1996) *GIS by ESRI: Arc View GIS Manual.* Environmental Systems Research Institute, Inc. New York, U.S.A.

FAC (Flora Advisory Committee) (1994) *Native Higher Plant Taxa which are Rare or Threatened in Tasmania.* Parks and Wildlife Service, Hobart.

Gallagher, S. (1997) *Coal River Catchment – Natural Resource Assessment.* Part of a study undertaken for the development of a Catchment Management Strategy for the valley. 65 p.

Garnett, S. (1992) *Threatened and Extinct Birds of Australia.* Royal Australasian Ornithologists Union, Hawthorne East, Victoria and Australian National Parks and Wildlife Service, Canberra.

Garret, G. (1999) Personal Communication. GIS photogrammetrist, Department of Primary Industries, Water and Environment, Tasmania. October, 1999.

Goede, A. (1998) *Quaternary studies of caves and coasts. A collection of published papers and critical review.* Volume 2,. PhD thesis, Department of Geography and Environmental studies, University of Tasmania. 351 p

Goede, A. (1999) Personal communication. Honorary research fellow, Department of Geography and Environmental Studies, University of Tasmania.

Goldin, P. (1980) Edited collection. *Coastal Tasmania: An environmental study.* Vol. **1**. Tasmanian Conservation Trust Inc. 141 p.

Goldsmith, V. (1978) Coastal Dunes. In: *Coastal Sedimentary Environments.* Davis, R.A. Jr. (Ed.). Springer-Verlag, New York. 171-235.

Greeley, I. Blumberg, D.G. and Williams, S.H. (1996) Field measurements of the flux and speed of wind-blown sand. *Sedimentology.* **43**: 41-52.

Greeley, R. and Iversen, J.D (1985) *Wind as a geological process on Earth, Mars, Venus and Titan.* Cambridge University Press, Cambridge.

Haber, E. (1998) *Invasive Plants Alert: 1997-1998 Report.* Invasive Plants of Canada Project. National Botanical Services, Ottawa. http://infoweb.magi.com/~ehaber/9_98rpt.html. Accessed on 26/2/99.

Haigh, M.J. (1977) Use of erosion pins in the study of slope evolution. Technical Bulletin No. 18., *British Geomorphological Research Group.* **11**: 31-49.

Hardisty, J. (1990) *Beaches: Form and process.* Academic Division of Unwin Hyman Ltd, USA.

Heathcote, R.L. (1983) The Geomorphological role of vegetation in desert dune systems. *In*: Thomas, S.G. and Tsoar, H.(Eds.) (1990) *Vegetation and Erosion: Processes and environments.* John Wiley and Sons, England. 471-487.

Hertling, U.M. (1997) Ammophila arenaria (L.) link (Marram grass) in South Africa and its potential invasiveness. PhD thesis, Departments of Botany, Rhodes University. 279 p.

Hesp, P. (1981) The formation of Shadow Dunes. *Sedimentary Petrology.* **51**:101-112.

Hesp, P. (1983) Morphodynamics of incipient foredunes in N.S.W. Australia. *In*: Brookfield, M.A. and Ahlbrandt, T. (Eds.) *Eolian Processes and Sediments.* Elsevier, Amsterdam. 11: 325-342.

Heyligers, P.C. (1985) The impact of introduced plants on foredune formation in south-eastern Australia. In: *Proceedings of the Ecological Society of Australia.* **14**: 23-41.

Hurburgh, W. (1973) *The Geomorphology of the Dodges Ferry District.* BSc. Honours Thesis, Department of Geography, University of Tasmania.

Illenburger, W. K. and Rust, I.C. (1988) Sand Budget for the Alexandria coastal dune field, South Africa. *Sedimentology.* **35**: 513-521.

Johnson, J.W., and Kadib, A.A. (1965) *Sand losses from a coast by wind action.* Ninth Conference on Coastal Engineering. 368-377.

Jones, C. (1997) *European Beachgrass – what is it?* http://www.nps.gov/redw/beach-gr.htm. Accessed on 26/2/99.Department of Interior National Park Service, Redwood National and State Parks.

Jungerius, P.D. and van der Meulen, F. (1988) The development of dune blowouts, as measured with erosion pins and sequential air photos. In: *CATENA Supplement 13 - an interdisciplinary Journal of Soil Science, Hydrology and geomorphology.* Amsterdam.

Jungerius, P.D. and van der Meulen, F. (1992) A geometrical approach to monitoring blowout development from aerial photographs using a Geographical Information System (GIS). *In:* Carter, R.W.G., Curtis, T.G.F. and Sheehy-Skeffington, M.J. (Eds.) *Coastal Dunes.* Balkema, Rotterdam.

Kadib, A.A. (1965) *A function for sand movement by wind.* Hydraulic Engineering Laboratory Wave Research Projects. University of California, Berkeley, California.

Kiernan, K. (1997) *Conserving Tasmania's Geodiversity and Geoheritage: The conservation of landforms of coastal origin.* Forestry Tasmania.

King, C.A.M. (1959) *Beaches and Coasts.* Edward Arnold Publishers Ltd., London.

Kirkpatrick, J.B. and Harris, S. (1995) *The conservation of dry coastal vascular plant communities.* Wildlife Scientific Report 94/1, Parks and Wildlife Service, Hobart.

Koch, R. (1999) Personal Communication. Ranger, Parks and Wildlife Service Tasmania, Seven Mile Beach.

Leaman, D. (1971) *The geology and groundwater resources of the Coal River Basin.* Underground Water Supply Paper No. 7. Department of Mines, Tasmania.

Loveday, J. (1955) Hobart reconnaissance soils map of Tasmania, sheet 82. CSIRO Division of Soils, Division Report 12/55, Adelaide.

Lubke, R.A., Hertling, U.M. and Avis, A.M. (1995) Is *Ammophila arenaria* (Marram grass) a threat to South African dune fields? *Journal of Coastal Conservation.* **1**:103-108.

Mansor, S. (1998) *Mapping Shannon Lagoon using Integrated GPS and Echo Soundings.* KGS 406, Department of Surveying, University of Tasmania.

McDonald, R.C., Isbell, R.F., Speight, J.G, Walker, J. and Hopkins, M.S. (1984) *Australian Soil and Land Survey Field handbook.* Inkata Press Pty.Ltd, Melbourne. 154 p.

McGlone, P. (1999) Birds also need their own beach space. In: *The Mercury.* August, 1999.

Moffatt, R. (1991) *Coastal Studies.* Wet Paper Publishing, Australia. 104 p.

Mooney, P. (1999) Personal communication. District Manager, Parks and Wildlife Service Tasmania, Seven Mile Beach.

Mowling, F.A. (1998) *Changes in the morphology of Waterhouse coastal dune system since 1949*. Grad. Dip. Env. Stud., Department of Geography and Environmental Studies, University of Tasmania.

Murray-Wallace, C.V. and Belperio, A.P. (1991) The last Interglacial shoreline in Australia – a review. *Quaternary Science Reviews.* **10**: 441-461.

Murray-Wallace, C.V. and Goede, A. (1991) Aminostratigraphy and electron spin resonance studies of late Quaternary sea level change and coastal neotectonics in Tasmania, Australia. *Zeitschrift fur Geomorphology.* **35** (50): 129-149.

Olson, J. S. (1958) Lake Michigan dune development: Plants as agents and tools in geomorphology. *The Journal of Geology.* **66** (4): 254-263, 345-351, 413-483.

Parks and Wildlife Service (1994) *Tasmanian Parks and Wildlife Service Reserve System: Categories, definitions and primary objectives.* Department of Environment and Land Management, Hobart.

Pemberton, M and Cullen, P. (1997a) *The adverse impacts of Marram grass on beaches and coastal dunes.* Tasmanian Community Landcare Conference Field Tours. Parks and Wildlife Service, Tasmania.

Pemberton, M. and Cullen, P. (1997b) *Coastal Dunes, their development and management in Tasmania.* Tasmanian Community Landcare Conference Field Tours. Parks and Wildlife Service, Tasmania.

Pemberton, M. (1999) Personal communication. Senior Earth Scientist, Geoconservation Section. Department of Primary Industry, Water and Environment.

Pethick, J. (1992) *An Introduction to Coastal Geomorphology.* Edward Arnold, USA. 126-143.

Platt, K.J. (1999) Personal communication. School of Surveying and Spatial Information Science, University of Tasmania.

Pye, K. (1983) Coastal Dunes. *Progress in Physical Geography: An international review of geographical work in the natural and environmental sciences.* 7(1): 531-550.

Rizos, C. (1996) *Principles and Practice of GPS surveying*. School of Geomatic Engineering, University of New South Wales, Sydney.

Sarre, R. (1989) The morphological significance of vegetation and relief on coastal foredune processes. *In*: Bremer, H. and Clayton, K.M (Eds.) *Zeitschrift Fur Geomorphologie.* Supplement band **73**. Coasts: Erosion and sedimentation.17-31.

Scanlon, A.P., Fish, G.T. and Yaxley, M.L (1990*) Behind the Scenery: Tasmanian landforms and geology*. Department of Education and the Arts, Tasmania.

Scwartz, M.L (1972) *Spits and Bars*. Stroudsburg, Pennsylvania. 452 p.

Sherman, D.J. and Hotta, S. (1990) Aeolian sediment transport: theory and measurement. *In*: Nordstrom, K.F., Psuty, N.P. and Carter, R.W.G (Eds.) *Coastal Dunes: Form and Process*. John Wiley and Sons Ltd. 16-35.

Short, A.D. and Hesp, P.A. (1982) Wave, beach and dune interactions in southeastern Australia. *Marine Geology*. **48**: 259-284.

Steane, D. (1999) Personal communication. Environmental Consultant, Hobart.

Summerfield, M.A. (1993) Coastal processes and landforms. *Global Geomorphology: An introduction to the study of landforms*. Longman Scientific and Technical, New York. 537 p.

Tasmap (1985) Carlton map sheet. 1:25,000. Mapping Division, Lands Department, Hobart.

Tasmanian Conservation Trust Inc. (1978) *Coastal Tasmania - A coastal Tasmanian Environment Study 1977-1978.* Hobart.

Thom, A.S. (1972) Momentum, mass and heat exchange of vegetation. *Quarterly Journal of the Royal Meterological Society.* **98**: 124-134.

Thom, B.G. (1978) *Holocene age structure of coastal sand barriers in New South Wales, Australia.* Department of Geography, University of N.S.W. 86 p.

Thom, B.G. (1981) Late Quaternary evolution of coastal sand barriers, Port Stephens-Myall Lakes area, Central N.S.W., Australia. *Quaternary Research.* **15**: 345-364.

Thomas, D.S.G. and Tsoar, H. (1990) The geomorphological role of vegetation in desert dune systems. *In*: Thornes, J.B. (Ed.) *Vegetation and erosion: Processes and environments.* John Wiley and Sons, New York. 471-486.

Tsoar, H. (1989) Linear dunes – forms and formation. In: *Progress in Physical Geography: an international review of geographical work in the natural and environmental sciences.* **13(4)**: 507-523.

VAC (Vertebrate Advisory Committee) (1994). *Native Vertebrates which are Threatened in Tasmania.* Parks and Wildlife Service, Hobart.

Van de Geer, G. (1972) *Marion Bay Shoreline Morphology.* BA Honours thesis. Department of Geography, University of Tasmania.

Viles, H.A. (1988) *Biogeomorphology.* Basil Blackwell Publishing, Oxford, U.K.

Walton, T. L. (1998) Least Squares Filtering to assess shoreline change signatures. *Journal of Coastal Research.* **14(4)**: 1225-1230. Royal Palm Beach Florida.

Wiedemann, A.M. (1987) *The ecology of European beachgrass (Ammophila arenaria (L.) link). A review of the literature.* Technical Report No. 87-1-01. Oregon Department of Fish and Wildlife. Nongame Wildlife Program.

Wiedemann, A. M. (1988) *Ammophila arenaria* (L.) Link (European beach grass, Marram grass) on the northwest coast of North America. *Botanical Electronic News – BEN*: **183**. http://www.ou.edu/cas/botany-micro/ben/ben183.html. Accessed on 26/2/99.

Wiedemann, A.M. (1999) Personal communication via electronic mail, 4/3/99. Evergreen University, North America.

Wiedemann, A.M. and Pickart, A. (1996) The *Ammophila* problem on the north-west coast of North America. *Landscape and Urban Planning*. **34**: 287-299.

World Resources Institute (1992) *Global Biodiversity Strategy*. World Conservation Union and United Nations Environmental Programme.